

SOLAR TECHNOLOGY IN THE FEDERAL REPUBLIC OF GERMANY

Bundesverband Solarenergie (BSE)

{NASA-TM-75634} SOLAR TECHNOLOGY IN THE N79-24439  
FEDERAL REPUBLIC OF GERMANY (National  
Aeronautics and Space Administration) 75 p  
HC A04/MF A01 CSCI 10A Unclass  
G3/44 20932

---

Translation of "Solartechnik in der Bundesrepublik Deutschland,"  
"Bundesverband Solarenergie, BSE, Report, Athens, November 10, 1978,  
Evgenidis Foundation, pp 1-38"



1. Report No. NASA TM 75634	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle  SOLAR TECHNOLOGY IN THE FEDERAL REPUBLIC OF GERMANY		5. Report Date May 1979	
		6. Performing Organization Code	
7. Author(s)  Bundesverband Solarenergie		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address  Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASW-3199	
		13. Type of Report and Period Covered  Translation	
12. Sponsoring Agency Name and Address National Aeronautics and Space Adminis- tration, Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes  Translation of "Solartechnik in der Bundesrepublik Deutschland," Bundesverband Solarenergie, BSE, Report, Athens, November 10, 1978, Evgenidis Foundation, pp 1-38			
16. Abstract  A series of papers dealing with the status of solar research and development in the Federal Republic of Germany are presented at a conference in Greece with the object of promoting international cooperation in solar energy utilization. The reports focus on solar collector designs, solar systems, heat pumps, solar homes, solar cooling and refrigeration, desalination and electric power generation. Numerous examples of systems produced by German manufacturers are illustrated and described, and performance data are presented.			
17. Key Words (Selected by Author(s))		18. Distribution Statement  Unclassified-Unlimited	
19. Security Classif. (of this report)  Unclassified	20. Security Classif. (of this page)  Unclassified	21. No. of Pages  74	22. Price

## SOLAR TECHNOLOGY IN THE FEDERAL REPUBLIC OF GERMANY

### Bundesverband Solarenergie (BSE)

The changes that have occurred recently in the energy market /1\* are responsible in large measure for increased research and development efforts in the more efficient utilization of energy.

In addition, great efforts are being made worldwide to utilize the energy of the sun, the energy stored in the earth's interior, and the energy contained in the surrounding air, wind and tides as an alternative to such "conventional" primary energy sources as coal, oil, natural gas and nuclear energy.

Numerous firms in the Federal Republic of Germany have developed new techniques, especially in the area of solar energy, which enable the use of regenerative energy sources in various areas.

These firms have founded the National Solar Energy Association ("Bundesverband Solarenergie," or BSE), the purpose of which is to explore, test and harness the potentials of solar energy utilization.

The BSE also seeks to address technical problems of common interest, inform the public on the possible applications of solar energy, and promote cooperation with other nations.

---

\* numbers in the margin indicate pagination in the foreign text.

## Table of Contents

/3

	Page
Introduction Dr.-Ing. B. Stoy, Essen	11
Solar Collectors and Systems Dipl.-Ing. H. Schön, Hilzminden	7
Heat Pumps Dr.-Ing. F. Scharf, Stuttgart	17
Solar Houses and Installations Dr. rer. nat. H. Horster, Aachen	26
Solar Cooling Dr. rer. nat. H. Märhenkel, Walldorf	35
Seawater Desalination with Solar Energy Dr.-Ing. A. Ziemer, Friedrichshafen	42
Solar-Thermal Power Generation Dipl.-Ing. J. E. Feustel, Munich	50
Photovoltaic Power Generation Dr.-Ing. E. F. Schmidt, Wedel	61

## INTRODUCTION

/5

B. Stoy

On behalf of the members of the National Solar Energy Association, I wish to thank you for accepting our invitation. We are most pleased with the participation of prominent representatives of the Greek economy, science and industry, with whom we hope to initiate an intensive exchange of experience and establish close cooperative ties in the utilization of solar energy.

We are especially pleased with the participation of Dr. Propp, director of the Federal Ministry for Research and Technology of the Federal Republic of Germany, whose presence here expresses the traditional good cooperation between this Ministry and the National Solar Energy Association. I would also like to thank our Greek colleagues, and especially Professor \_\_\_\_\_ of the University of Patras for his support of this conference.

The great interest of both the Greeks and Germans in prompt, well-founded work on the development, testing and operation of solar energy systems is also demonstrated by the fact that the Greek authorities, power supply companies, firms and branch concerns of Association members, as well as the Embassy of the Federal Republic of Germany in Athens have contributed greatly to the preparation of this conference.

We can be certain that the Greek and German government will sanction all steps toward solar energy utilization and, where necessary, will promote such steps by appropriate measures.

I would like first to introduce the National Solar Energy Association, its goals and various spheres of activity.

In 1975, when the first industrial activities in solar energy utilization were begun in the Federal Republic of Germany, the leading concerns in this area founded a council for the study of solar energy. This was expanded in early 1978 into the National Solar Energy Association. At present the Association membership is comprised of 23 competent concerns. The membership requirements ensure that the Association will include only those firms whose products are of a high, state-of-the-art quality according to international standards.

The goal of the National Solar Energy Association, or BSE, is to explore, test and harness the potentials of solar energy utilization, address technical problems of common interest, instruct the public on the application and performance of solar energy systems, and promote cooperation with other nations.

With regard to the last point, cooperation with other nations, I would like to make some additional comments, especially in view of today's meeting. It is true that the member firms of the BSE, which are large, powerful, highly active and in some cases internationally known, have been exploring or establishing foreign contacts in the solar sector for some time. However, these individual steps would achieve a broader base if all BSE member firms were able to discuss their many possibilities jointly with foreign partners and present the latest developments.

This concept is realized by the present conference and the discussions that follow. Further conferences in other countries are planned for future years. The Athens conference was proposed for 1978 because the Federal Republic of Germany already enjoys numerous contacts with your sun-rich country, and the distance between our countries is relatively small in comparison with other solar zones of the earth.

The efforts which we are undertaking jointly today to promote solar energy utilization are investments in the future. Those countries which possess a high level of technology have recognized the signs of the times and are concentrating a portion of their engineering potential, inventive spirit and financial resources on the harnessing of solar energy. There is little question that this energy source has become man's "dream energy" within the last few years: This inexhaustible source of energy can be exploited without the reckless depletion of hydrocarbon resources, without thermal or chemical pollution of the atmosphere, and without rising energy costs; for the energy of the sun costs nothing. And yet it is said, and with good reason at present, that free energy of this kind is the most expensive energy; for the installation, servicing and maintenance of solar systems have demanded so much capital that the useful energy produced, such as space heat, process heat, electricity or hydrogen, has generally been more costly than that produced by water power, coal, oil, gas or nuclear energy.

However, it is clear that these cost ratios will change in the near future, and the installation costs of solar systems will be reduced by mass production.

Classical energy sources are becoming scarce and thus increasingly more expensive. The possibilities of water power are very limited. The high labor costs of bituminous coal production are leading to ever-greater increases in its energy cost. Petroleum -- at present the dominant primary energy source -- has become one of the greatest uncertainty factors with regard to its availability and future price development. Natural gas cannot cover a significant portion of the energy demand and is, moreover, tied to oil price developments. The safety requirements for generating power from nuclear energy and the costs of disposal facilities will probably lead to increasing reliance on solar

energy in sun-rich countries with relatively sparse populations. /6

Man's growing energy demands on the one hand and the oil shortage expected in one to two decades on the other will have an even greater impact than changing cost ratios. Twenty percent of the world population -- and Greece is included among this 20% -- accounts for 80% of the world energy demand. The rest of mankind has a very low standard of living or is barely able to earn a living wage. The energy demands of this vast majority will increase in this century, particularly since population growth is most marked in impoverished countries. But these countries will be less and less able to pay rising oil prices in the future, and nuclear energy is a viable alternative only in certain cases.

With petroleum, the path to technological progress and a high standard of living was accessible to only a few countries -- the "industrial nations" of today. It could be concluded, pessimistically perhaps but with some justification, that the developing nations, and thus to the overwhelming majority of mankind, will no longer be able to follow the petroleum path to progress. Consequently, every effort must be made now, while there is time, to exploit economically the inexhaustible supply of solar energy. We must do this to contribute to the stability of world peace, to ensure a better life for the people in underdeveloped countries, and to protect the export trade of the industrial nations from substantial losses.

Many of these nations, such as the Federal Republic of Germany, possess all the technological and financial resources for this task but lack the necessary climatic conditions under which a large portion of the solar energy systems on this planet will one day be operated. The obvious solution is cooperation with a country, such as Greece, which is also at a relatively high technical and economic level, but whose solar energy resources

are much greater than our own, and whose economic and political climate hold much promise for a cooperative venture based on the principles of the free market economy.

I can assure you, ladies and gentlemen, on behalf of all the persons from our country who are participating in this conference, that we would most gratefully welcome a closer cooperation with Greek business, science and government. Success is always achieved when the parties involved can contribute to it and profit by their joint action. Considering the advantages which Greece has to offer the Federal Republic, and the possibilities which the Federal Republic offers Greece, the steps begun here are sure to bring success.

The technical concepts which are being pursued by BSE member firms and the projects which are in the testing or production stages will be discussed in the papers which follow. In general, it may be said without exaggeration that the German solar industry has attained world recognition for its high level of development. It has even become a leader in certain areas, making the Federal Republic the most important partner of the United States in terms of technology transfer. Examples of this are such varied processes as the manufacture of polycrystalline silicon cells for space travel or the integrated heating of solar-heated swimming pools.

The initial phase of our cooperation with Greece will be marked primarily by solar heating systems. Solar cooling for food preservation or air conditioning will represent a further area of application which is important for many regions in Greece. The prospects for a fruitful cooperation are excellent. May I therefore express the hope that the discussions and events of November, 1978, in Athens will represent the first step toward a long, active and successful partnership for the benefit of the

participating concerns, for the broadening of scientific knowledge, for the expansion of trade and the exchange of goods, and finally for the prosperity of the peoples of both countries.

H. Schön

In this paper I would like to present to you the solar collectors and systems currently marketed in Germany by the member firms of the BSE.

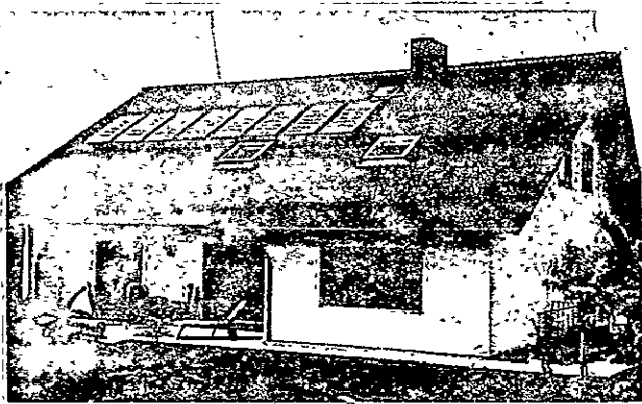


Fig. 1

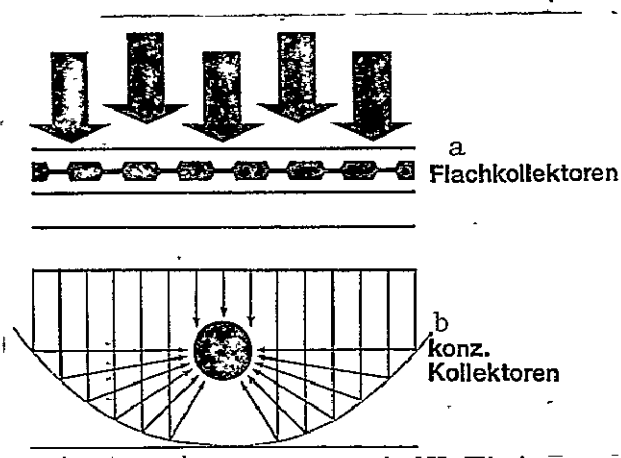


Fig. 2

Key: a - Flat-plate collectors;  
b - Concentrating collectors.

The essential and most visible component of a solar energy system is the solar collector, which transforms the radiant energy of the sun into thermal energy. It is a device for the direct utilization of the virtually inexhaustible energy of the sun.

The thermal energy captured in solar collectors can be used for water heating, swimming pool heating, space heating (in low-temperature range) and, at higher operating temperatures, for cooling and seawater desalination.

There are at present two main types of solar collector designs:

1. Flat-plate collectors  
(including flat-roof and integrated collectors)

## 2. Concentrating collectors.

Flat-plate collectors are currently produced in greater quantities and are suitable for generating temperatures in the low and intermediate ranges. Concentrating solar collectors operate mainly in the high temperature range, but also in the intermediate range.

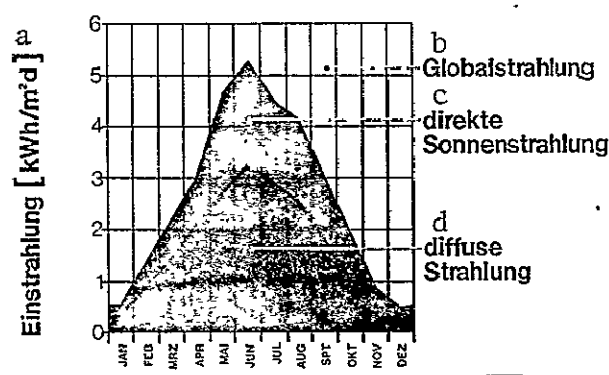


Fig. 3

Key: a - Insolation ( $\text{kWh/m}^2\text{d}$ );  
b - Global radiation; c - Direct solar radiation; d - Diffuse radiation.

Solar radiation strikes the earth's surface at an intensity of about  $1000 \text{ W/m}^2$ . This "global radiation" is composed of direct solar radiation and diffuse sky radiation. Diffuse sky radiation is produced by the scattering of solar radiation in the atmosphere. It comes from all directions, casts no shadow and therefore cannot be concentrated. Thus, concentrating collectors can utilize only direct sunlight, while flat-plate collectors utilize the total global radiation.

In the non-industrial sector (i.e., domestic water heating, swimming pool heating, space heating), flat-plate collectors are usually employed. There are two basic designs for flat-plate collector systems:

1. Direct heat transfer (at very low temperatures, for example) and
2. Indirect heat transfer via heat exchangers
  - 2.1 in the storage tank
  - 2.2 external transfer

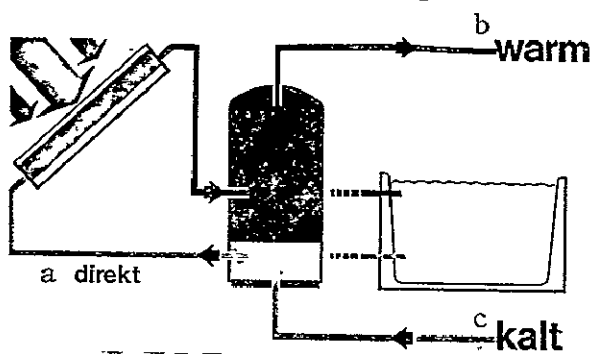


Fig. 4

Key: a - Direct;  
b - Hot; c - Cold.

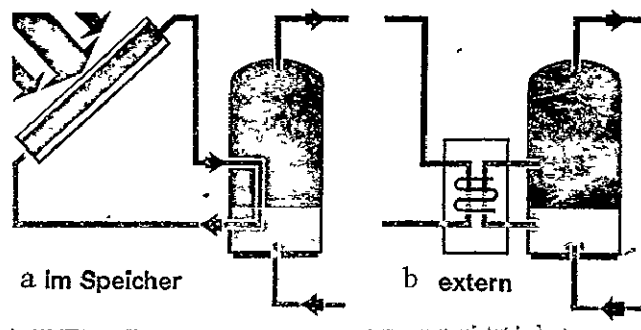


Fig. 5

Key: a - In the storage tank;  
b - External transfer.

In direct heat transfer, the water for domestic use flows /8 through the absorber of the collector. In indirect heat transfer, the circulation loop is closed. Higher temperatures are attained, and the liquid heat transfer medium used in this primary loop must retain its liquid state over the range from  $-40^{\circ}\text{C}$  to about  $+170^{\circ}\text{C}$  and must also protect the closed loop from corrosion. The closed primary loop has all the advantages known from heating technology. Direct heat transfer is certainly more economical, but indirect transfer is more universally applicable.

The mode of heat transfer and the various applications determine the design and choice of materials for the flat-plate collector.

The heart of the collector is the absorber.

Absorbers are made from steel, aluminum, copper, plastic, stainless steel or from combinations of aluminum and copper or aluminum and stainless steel.

The absorber should absorb as much radiant energy as possible and emit as little as possible. The conversion of radiant energy subjects the absorber to high thermal and mechanical stresses.

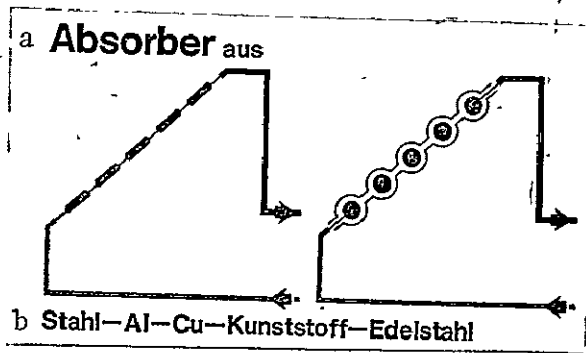


Fig. 6.

Key: a - Absorber made from;  
b - Steel-Al-Cu-plastic-stainless steel.

Stagnation temperatures up to about 170° C can occur. Flat black paints have proved suitable as coating materials, but absorption values can be improved by the use of selective surfaces. However, it is important in such cases that the selective coating be applied by economical methods (e.g., electrostatic techniques). Selective enamel coatings have also been employed in Germany.

With selective coatings, higher operating temperatures can be achieved, and even flat-plate collectors can be used for cooling and seawater desalination.

The heat transfer medium should come into contact with the absorber over as large an area as possible. Small absorber volumes and thin-walled conductive materials enhance the thermal response of the collector.

The flat-plate collector is fitted with one or two covers on the side facing the sun. The number of covers required depends on the application of the solar system and especially on the particular climatic zone. The covers must be transparent to the wavelengths of solar radiation. They are made of glass, plastic sheet or film, or combinations of them. The covers should be as opaque as possible to re-emitted radiation (greenhouse effect).

The covers may be flat or convex; convex covers are more glare-free.

The danger of breakage and susceptibility to degradation must

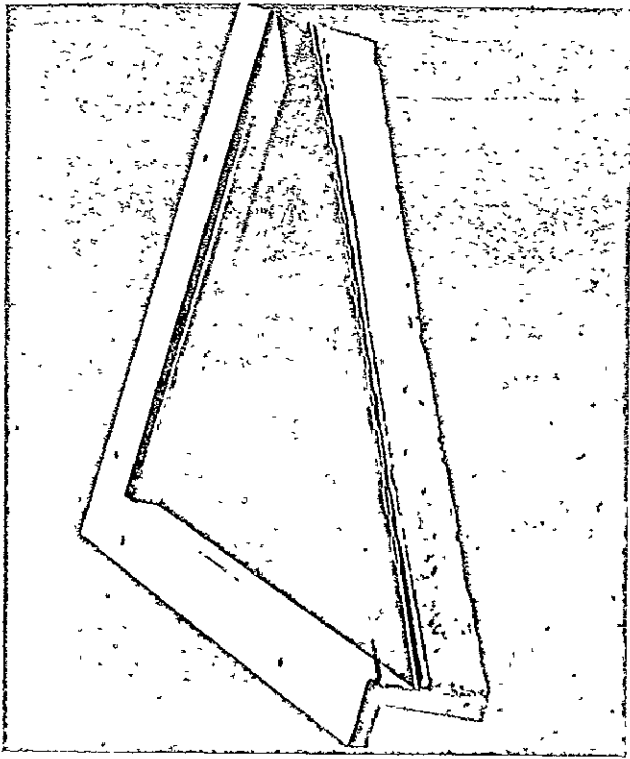


Fig. 9

available on enclosed plastic tubs made of fiberglass-reinforced plastic.

Flat-plate collectors should be convenient to handle, and should have a long service life (20 years).

These requirements give us the criteria for an economical collector design. /9

Active absorber areas of 1.5 to 2.5 m<sup>2</sup> and weights of 35 to 45 kg have proved to be optimal service values.

Flat-plate collectors should be so designed that they can be built into roofs or mounted atop flat roofs. German industry offers a wide variety of installation aids, which permit the rapid, trouble-free and thus economical installation of flat-plate collectors.

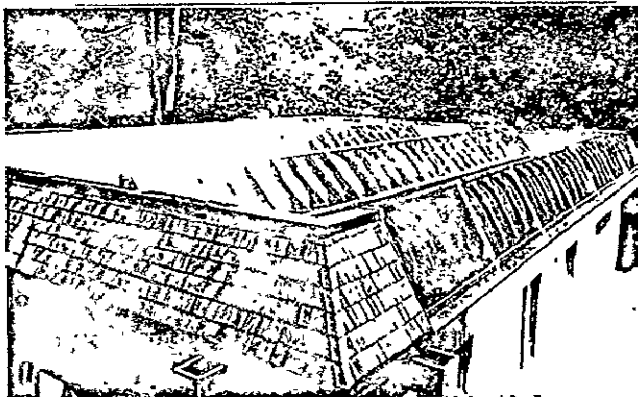


Fig. 10

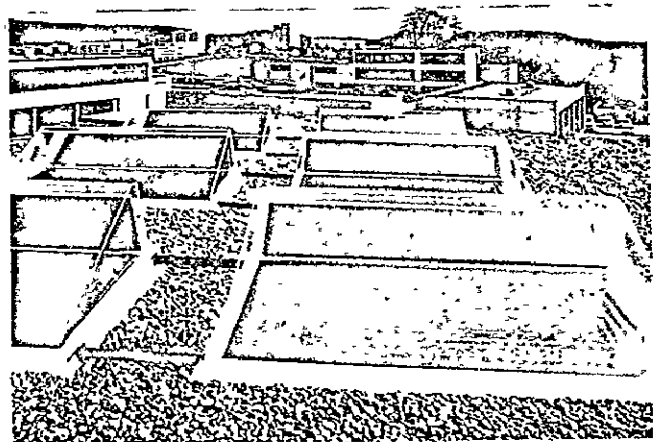


Fig. 11

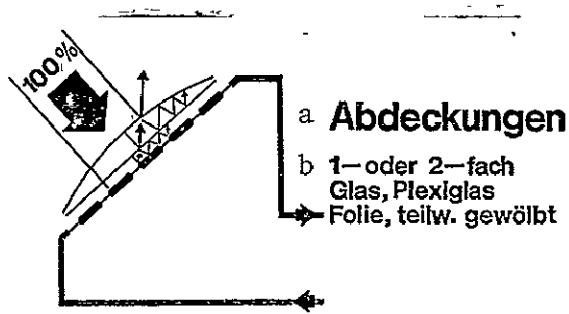


Fig. 7

Key: a - Covers; b - 1 or 2 sheets of glass, plexiglass, film, partially convex.

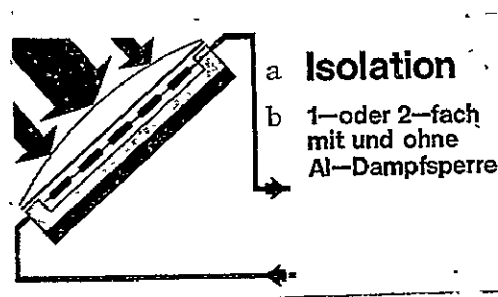


Fig. 8

Key: a - Insulation; b - Single or double, with or without Al vapor seal.

also be taken into consideration during the selection of materials.

To minimize the amount of thermal energy lost from the absorber to the environment, the absorber is backed with insulation. We have examples of 1- and 2-layer insulation with or without a metallic vapor seal. The high stagnation temperatures must be taken into consideration. For this reason, mineral insulating materials which can withstand temperatures above 200° C are often placed in direct contact with the absorber.

The frame for holding the absorber, the covers and the insulation must be made of a corrosion-resistant material.

There are examples of frames made of:

1. galvanized steel
2. aluminum, with or without surface treatment
3. plastic.

One member firm in Germany has employed galvanized steel tubs for housing the collector components. Test results are also

A special type of flat-plate collector is the flat-roof collector, which is equipped with an adjustable reflecting mirror to increase the energy yield.

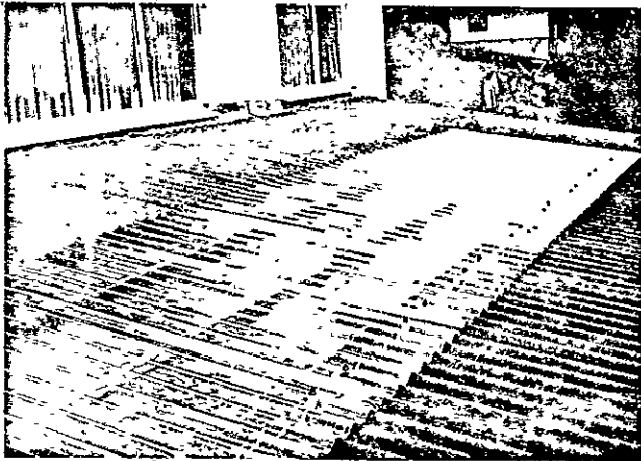


Fig. 12

Two German member firms offer a practical separation between the cover and the absorber including insulation. This permits the collector to be truly roof-integrated. The outer cover consists of glass or plexiglass shingles. The absorber is built into the roof structure and is backed by insulation.

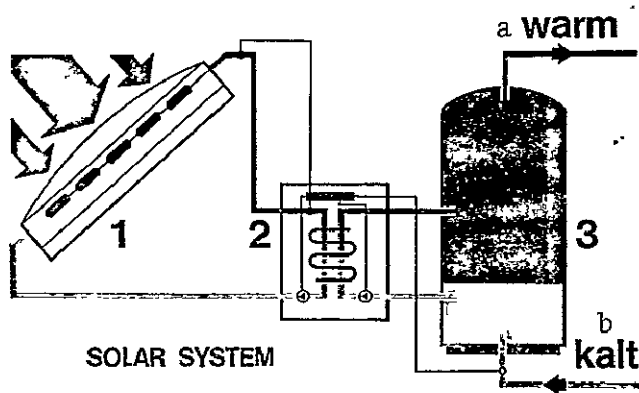


Fig. 13

Key: a - Hot; b - Cold.

#### System Control and Storage:

Many German firms offer solar collectors as a component of a coordinated solar energy system, for either water or space heating, either bivalent or trivalent, with electricity or other available heating systems.

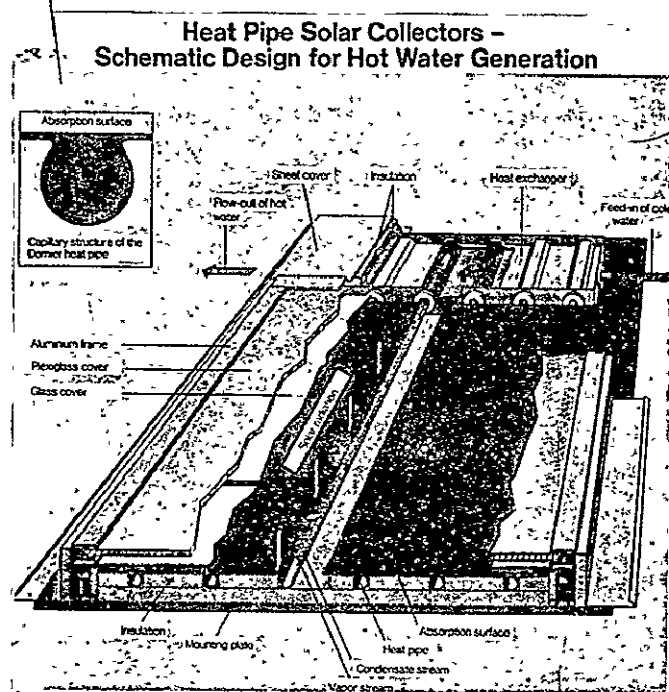
The coordinated system includes a control component designed for the specific application of the system (e.g., water heating or space heating). Systems are available in which the control component is part of an integrated installation unit.

Storage units are available with or without heat exchangers, /10

and with or without integrated auxiliary electric heating.

#### Other Flat-Plate Collectors:

1. Vacuum collectors, in which the body consists of evacuated, partially-mirrored glass tubes. These collectors are naturally expensive, but have favorable start-up properties. They start to function at an insolation of only  $100 \text{ W/m}^2$ , as compared with  $200 \text{ W/m}^2$  for flat-plate collectors.



#### 2. Heat-pipe collectors:

These collectors have evacuated aluminum tubes containing a small quantity of heat transfer fluid with a low vaporizing point, normally freon. This fluid vaporizes under sunlight, condenses in the heat exchanger, and returns to the collector to be vaporized again. Operating temperatures up to  $200^\circ \text{C}$  can be achieved with this collector. It can thus be used for cooling and seawater-desalination purposes.

Fig. 14

The second main type of collector, the concentrating type, utilizes only direct radiation and can generate temperatures up to  $200^\circ \text{C}$ .

These collectors are understandably more expensive than flat-plate collectors, but are very well suited for providing energy for technical processes, cooling, air conditioning, seawater desalination and electric power generation. To increase

their efficiency, these collectors are steered to follow the sun.

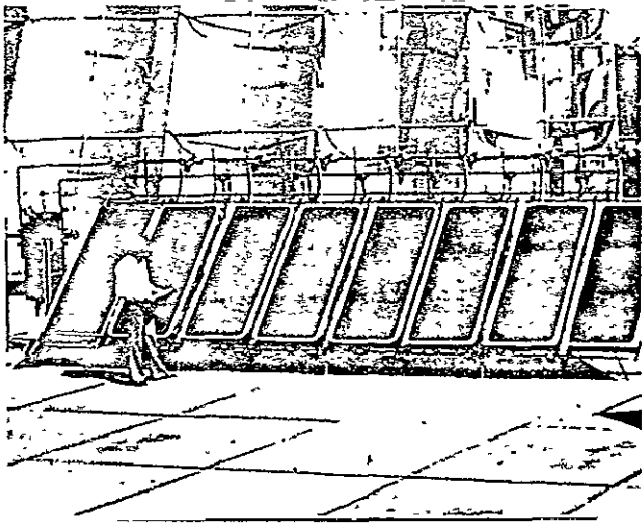


Fig. 15

Fig. 15 shows the test stand for the long-term performance testing of collectors in Munich, Germany. In the background is the test stand for cylindrical parabolic test collectors.

Fig. 16 shows a semi-automatic welding line for the manufacture of absorbers. In the background is a large-scale surface-treatment unit. The

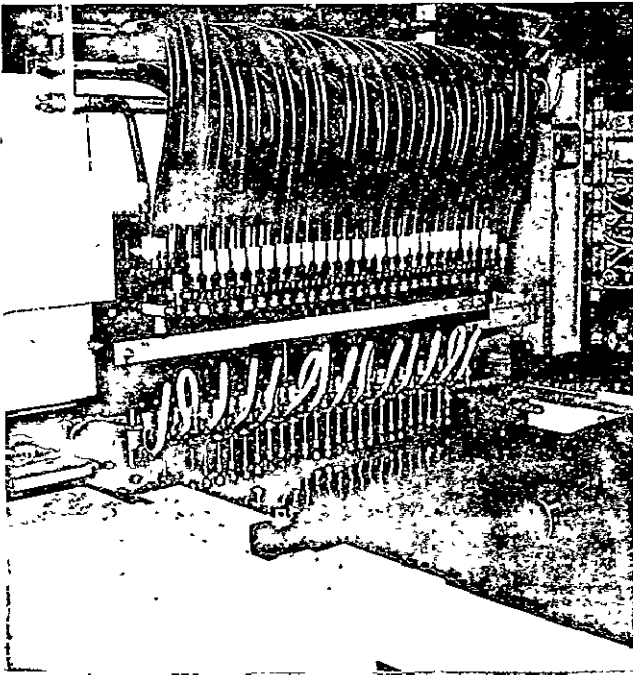


Fig. 16

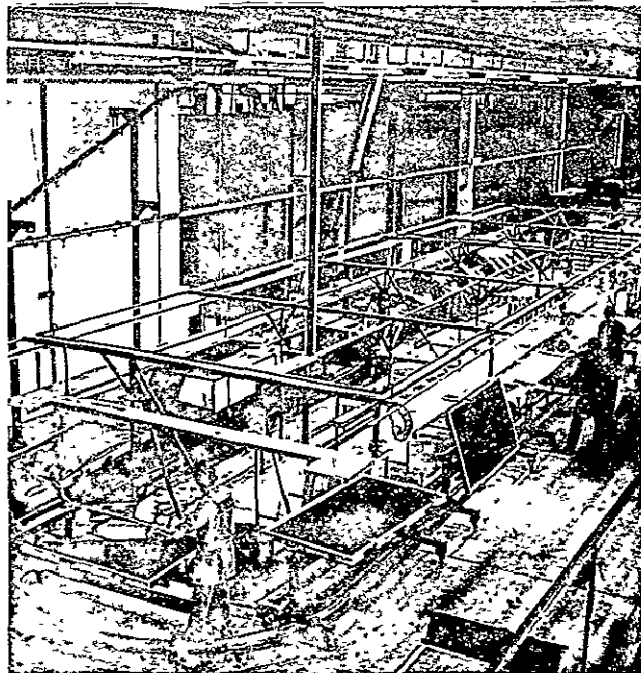


Fig. 17

production line can handle both steel and stainless steel, and the electrostatic system is capable of applying selective paint coatings.

Fig. 17 shows the final assembly line for flat-plate collectors with a double cover and double insulation with an aluminum vapor seal. The frame is made of aluminum. The upper plexiglass cover is convex. The assembly fixtures can be rotated  $360^\circ$  about their longitudinal axis.

Now more than ever, solar systems with or without heat pumps are of considerable economic, social and political significance.

Through the large-scale production of collectors and system designs for water and space heating, it is now possible to achieve an economical ratio of cost to benefit, and thus to market solar /11 systems successfully. For political and politicoeconomic reasons, however, efforts by private enterprise should be supported in part by government funding measures.

F. Scharf

Introduction

The heat pump is of importance in solar energy utilization for two reasons: First, it enables the efficiency of solar heating systems to be improved, and second, it enables cost-free ambient heat, which comes ultimately from the sun, to be utilized for heating purposes.

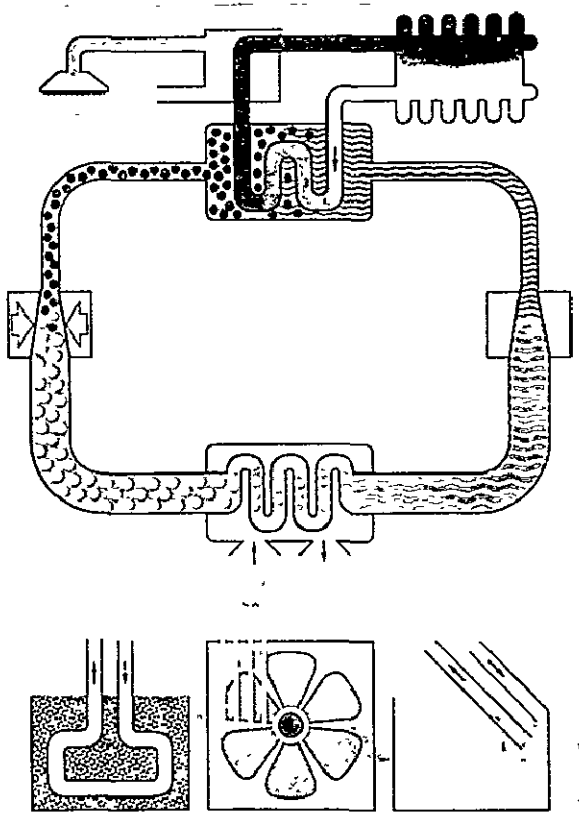


Fig. 1

Method of Operation

The function of a compression heat pump is shown schematically in Fig. 1. The compressor draws refrigerant vapor from the evaporator, compresses it to a higher pressure and delivers the vapor, now hot, into the condenser. The medium flowing around the evaporator, in this case water, supplies heat for the evaporation of the refrigerant and is cooled in the process. In the condenser, heat for space and water heating is released by liquefaction of the vapor. The refrigerant is re-expanded through a valve, where-

upon the cycle is repeated. The process described here has been employed for decades in compression refrigeration equipment in

refrigerators and freezers and thus represents a proved technology.

Most of the heat in heat-pump systems is extracted from such sources as river water, ground water, the soil or the surrounding air. The electric power input serves mainly to drive the compressor and contributes only a part of the thermal output.

A heat pump thus delivers a multiple of the electric energy input as heat. This property is characterized by the coefficient of performance (COP), which is the ratio of the thermal output of the heat pump to the electric energy consumed.

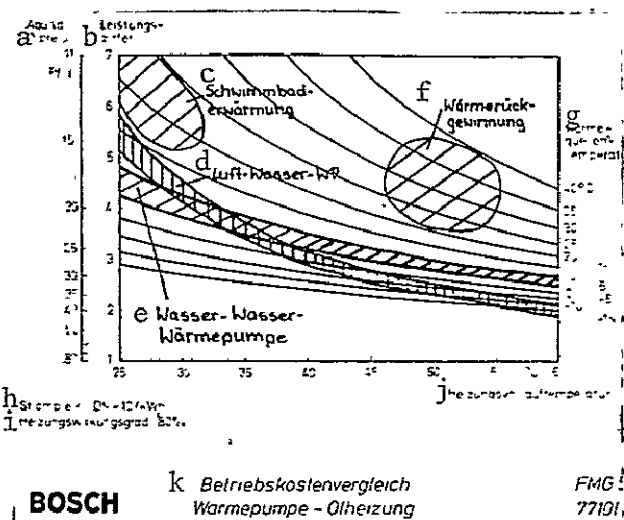
As Fig. 2 shows, the lower the input temperature of the heating system, the more favorable the COP. This coefficient is also improved when the temperature of the heat source is raised. Depending on the climatic zone, heat source and heating system, the mean annual COP ranges from 2.5 to 3.5.

Since the COP is also a measure of the operating costs of a heat-pump heating system, Fig. 2 also shows the oil prices at which the costs of oil heating and heat-pump heating are equivalent. As the family of curves

Fig. 2

Key: a - Equiv. oil price; b - Coefficient of performance; c - Swimming pool heating; d - Air-to-water heat pump; e - Water-to-water heat pump; f - Waste heat recovery; g - Heat source temp.; h - Electricity cost = 10 DM/kWh; i - Heating efficiency 80%; j - Heating input temperature; k - Operating cost comparison between heat pump and oil heating.

indicates, only heat pumps with high COPs of 6-7 were competitive at low oil prices (below 0.13 DM/l). They were used to heat



outdoor swimming pools. The adjacent river served as the heat source. The utilization of industrial waste heat for water and space heating also represents a case with favorable COPs. Space

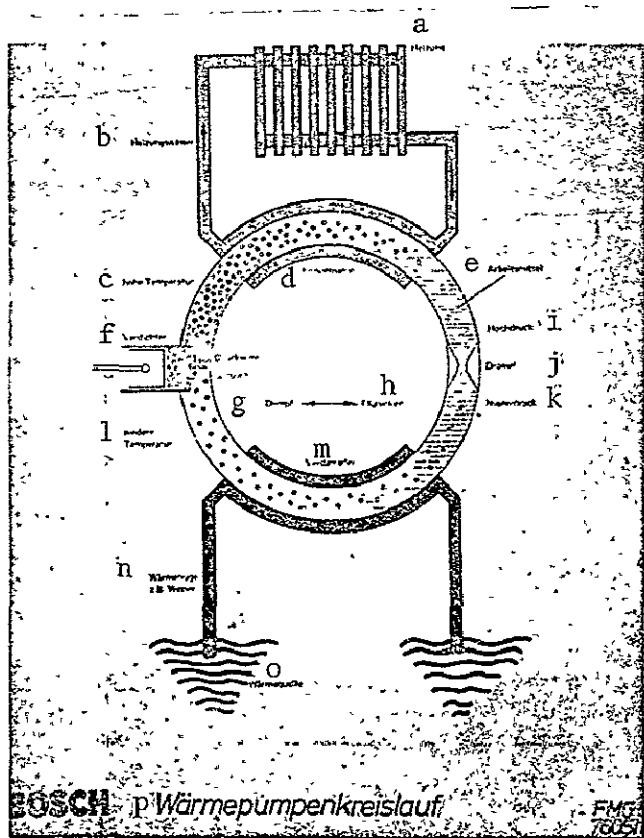


Fig. 3

Key: a - Heater; b - Heating duct; c - High temperature; d - Condenser; e - Working fluid; f - Compressor; g - Vapor; h - Liquid; i - High pressure; j - Valve; k - Low pressure; l - Low temperature; m - Evaporator; n - Heat carrier; o - Heat source; p - Heat pump cycle.

heating in the residential sector became feasible only at higher oil prices. Initially, water was the preferred heat source due to the more favorable COPs. Today, increased use is made of installations with air as the heat source, owing to its high availability. In this case the bivalent operating mode with oil heating is preferred up to air temperatures of about 3° C. Below 3° C the heating demand is met entirely by oil heating.

### Heat-Pump Heating Systems

Fig. 3 shows the design of a water-to-water heat pump with a compressor, evaporator, condenser and electric control. The electric power input is 3.8 kW. At a well-water temperature of 10° C and heating input temperature of 55° C, the thermal output of the system is 12 kW.

Each of the four houses in Fig. 4 is heated entirely by a water-to-water heat pump. A common well serves as the heat source. The individual houses are connected to the source via a ring conduit. /13

Fig. 5 shows the heat pump installed. At an electric power input of 4 kW, a thermal output of 14 kW is obtained. The input temperature for the floor heating is 45° C. Fig. 6 shows a bivalent air-to-water heat pump, which is combined with an oil heating system. The air exchanger and compressor are outdoors. The condenser is installed in the cellar next to the oil-fired boiler. Both heat sources can be alternately connected to the heating network and to the hot-water storage tank.



Fig. 4

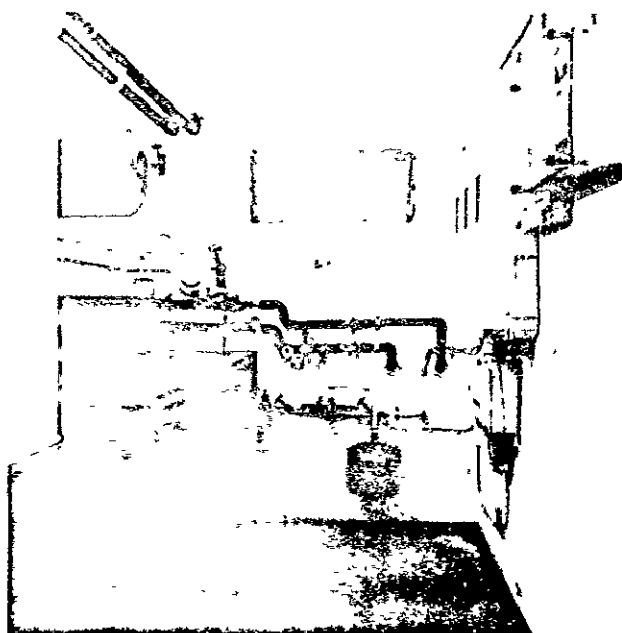


Fig. 5

In Fig. 7, the compressor and condenser of a bivalent air-to-water heat pump are contained in a single housing, installed in the cellar of a residence with floor heating. At a heating input temperature of 60° C and power input of 2.5 kW, the thermal output is 7 kW. Auxiliary heating is supplied by an electrical block storage unit. The air exchanger is mounted beneath the roof, as shown in Fig. 8. It draws air from the greater portion of the roof space, and thereby utilizes solar heat absorbed by the roof. The cooled air is exhausted between the rafters to the outside.

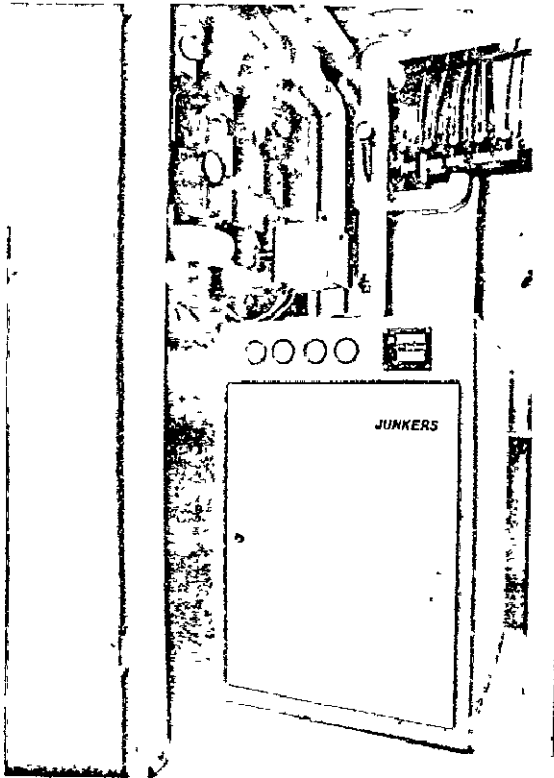


Fig. 6

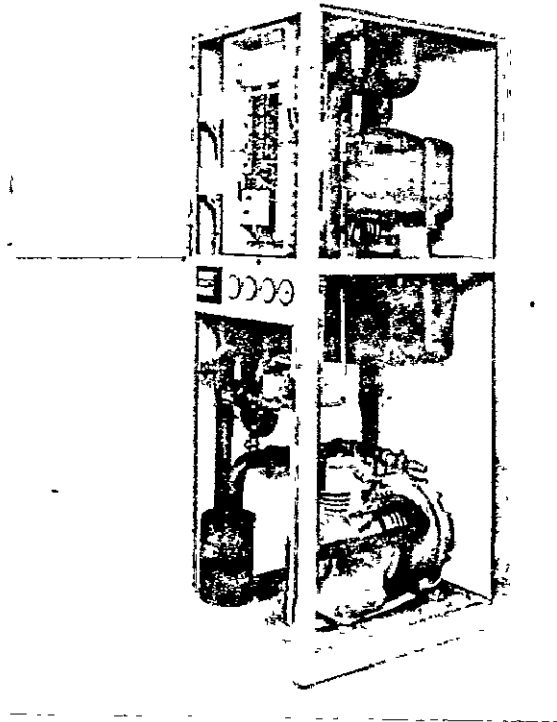


Fig. 7

#### Heat Pumps in Solar Systems

/14

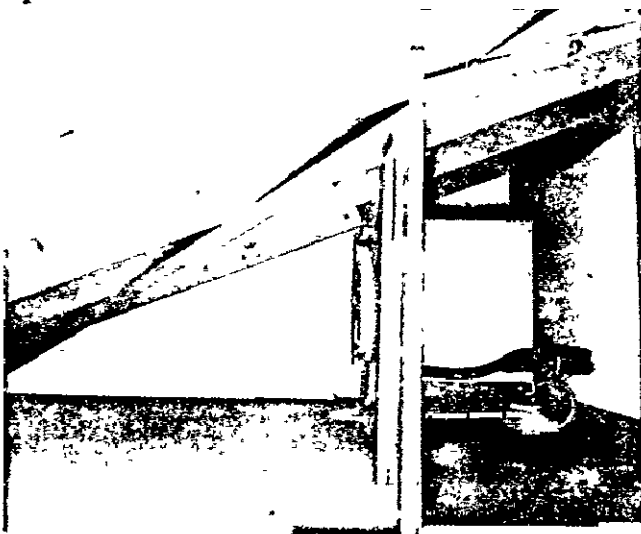


Fig. 8

The heat pump is used in solar heating systems to an increasing degree. As shown at the top of Fig. 9, the basic components of solar space- and water-heating systems are the solar collector, heat storage and auxiliary heater. The storage unit absorbs heat on sunny days when the temperature at the collector is higher than the temperature in the storage. It

can release heat to the heating network as long as its temperature exceeds the heating input temperature.

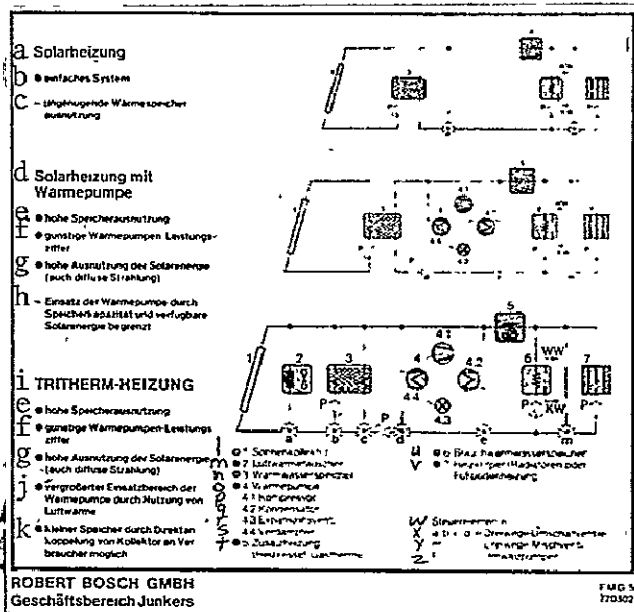


Fig. 9. The path to Tritherm heating.

Key: a - Solar heating; b - Simple system; c - Inadequate heat-storage utilization; d - Solar heating with heat pump; e - High storage utilization; f - Favorable heat-pump COP; g - High utilization of solar energy (incl. diffuse radiation); h - Use of heat pump limited by storage capacity and available solar energy; i - Tritherm heating; j - Range of heat-pump application increased by utilizing heat in the air; k - Storage size can be reduced by direct-coupling collector to load; l - Solar collector; m - Air heat exchanger; n - Hot-water tank; o - Heat pump; p - Compressor; q - Condenser; r - Expansion valve; s - Evaporator; t - Auxiliary heater (boiler);

[Key continued next page]

If this is not the case, conventional heating must be resorted to. The frequency with which this is necessary depends largely on the capacity of the heat storage, which is subject to strict limits for cost reasons and especially due to insulation requirements. Solar heat can be stored economically only over a period of several days, with the result that no more than 50% of the heating demand of a house can be met by a pure solar-collector heating system in Central Europe.

By installing a water-to-water heat pump, shown in the middle of Fig. 9, the proportion of auxiliary fossil-fuel heating can be substantially reduced. For one thing, the useful capacity of the heat storage is nearly doubled, since the water storage tank can now be cooled close to the freezing point. For another, the efficiency of the solar collector is improved. When the storage tank is cooled, cold transfer fluid is circulated through the collector. This leads

[Key to Fig. 9, continued]:

u - Service hot-water tank;  
v - Heater (radiator or floor heating); w - Control elements;  
x - 3-way reversing valves; y - 3-way mixer valve; z - Circulating pumps; WW - Hot water; KW - Cold water.

to smaller heat losses at the collector, so that a greater portion of the incident solar energy can be delivered to storage. This is particularly important when utilizing the weak, diffuse solar radiation

that often occurs in the winter.

The heat storage and solar-collector area can be further reduced by supplementing the heat pump with an air heat exchanger (Fig. 9, bottom) to utilize the outside air as a heat source on sunless days and at night. The operating time of the heat pump can be minimized by connecting the solar collector directly to the load during the summer. With such a combination of three heat sources, as represented by the Tritherm system, the proportion of auxiliary fossil-fueled heating can be reduced to 5%.

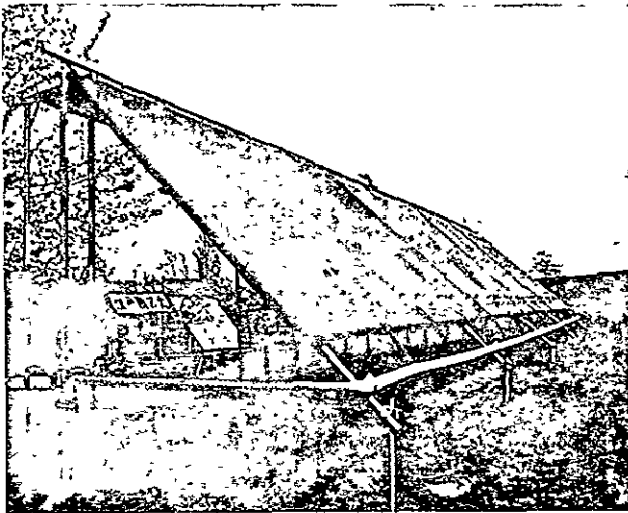


Fig. 10

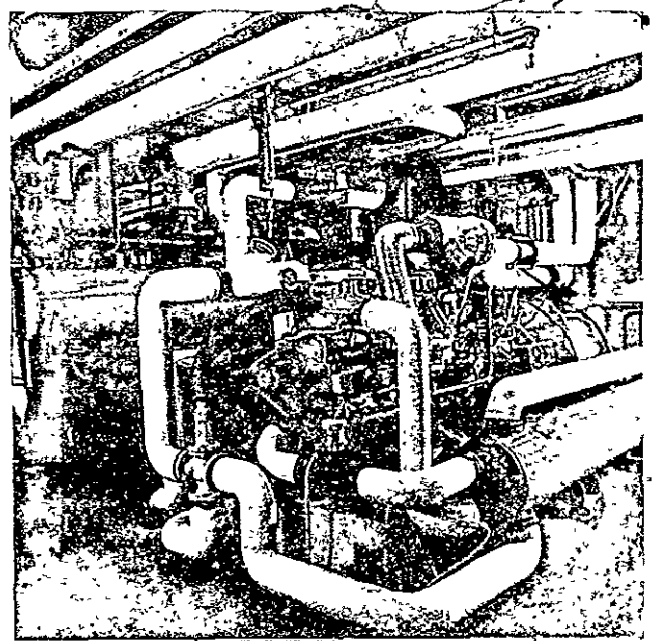


Fig. 11

The design of such a system can be greatly simplified by combining the function of the solar collector and the air heat exchanger in a single element.

This can be done by using solar absorbers which differ from ordinary solar collectors essentially by the absence of a transparent cover. Fig. 10 shows a test field with sloped-roof solar absorbers which are thermally insulated on one side. Large-area elements such as these can be used to fashion solar roofs which are similar in appearance to traditional roofs, but which, when combined with a heat pump, can utilize solar energy both directly and indirectly from the heat content of the surrounding air. /15

#### Energy Utilization with Heat Pumps

There has been increasing interest of late in the more complete utilization of the primary energy used for heating. Because some 70% of the primary energy is lost as waste heat in electric power generation and distribution, the heat pump, with its COP of 3, can make about 90% of the initial amount of primary energy usable for heating. This is about 1/3 more than the energy yield of a conventional fossil-fueled heating system.

By coupling the heat-pump compressor to a combustion engine, the primary energy is better utilized in comparison with the power plant/electric heat pump system. The main reason for this is that the waste heat from the engine and exhaust gases is also utilized for heating purposes. Fig. 11 shows a heat pump system with a 6-cylinder 109-kW gas engine, a piston compressor and the associated heat exchangers. The cooling-water heat exchanger is visible in the foreground, and the evaporator and condenser in the background. The thermal output is equal to 520 kW, 411 kW of which is contributed by the heat pump using ground water as the heat source, and 109 kW by waste heat from the engine. The system

is suitable for the heating of large building complexes and swimming pools. .

### Summary

The heat pump makes more efficient use of energy than modern conventional heating systems. It thus represents an important step toward solving the problems resulting from the rising costs and dwindling supplies of fossil fuels. In the long term, the heat pump will help to lessen our dependence on oil imports and slow the escalating primary energy demand.

H. Hörster

Since about 1973, studies have been conducted by German industry on solar houses and solar installations. These studies are funded in large part by the Federal Ministry for Research and Technology.

Commercial systems for solar water and space heating have also been available for about two years. Most of the studies done in Germany focus on the utilization of solar energy in buildings. The demand for "low-temperature heat" (the range below 100° C) is particularly great in this sector. The low energy density of solar radiation makes it well suited for conversion into low-temperature heat.

Unfortunately, the insolation conditions in Germany are poor compared with those in other countries. A south-facing surface inclined at a 45° angle receives an annual insolation of only about 1000-1200 kWh/m<sup>2</sup>.

Spain, by contrast, has annual values of more than 1500 kWh/m<sup>2</sup> for a similarly-oriented surface. Less sunny sites in the United States such as Washington, D.C., have an annual insolation of about 1400 kWh/m<sup>2</sup>; Madison, Wisconsin, has about 1600 kWh/m<sup>2</sup>.

These relatively unfavorable insolation conditions in Germany have made it necessary for German industry to develop extremely efficient solar systems, which are among the most advanced in the world. Another feature of German research is that studies are done not just on the direct utilization of solar energy, but also on total energy systems comprised of a solar system combined with

heat pumps and various storage concepts, sometimes incorporated into improved building designs. It is such combinations which promise the optimal utilization of solar energy.

In this paper I will deal first with solar houses, part of which are experimental, and then with some solar installations.

Since about 1973 the Philips Co. has been conducting studies at its research laboratory in Aachen, Germany, on the economical utilization of solar energy in buildings. High-efficiency collectors, which are excellently suited for solar cooling, as well as heat stores and solar systems are being studied. To enable the testing of newly-developed components and systems and permit comparisons with computer models, Philips has built an experimental house, which is undergoing exhaustive electronic analysis.

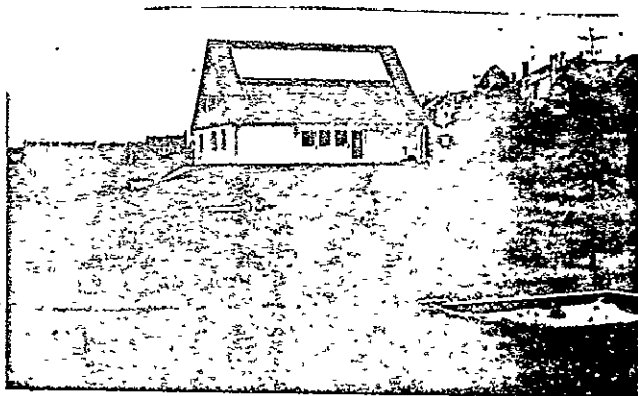


Fig. 1

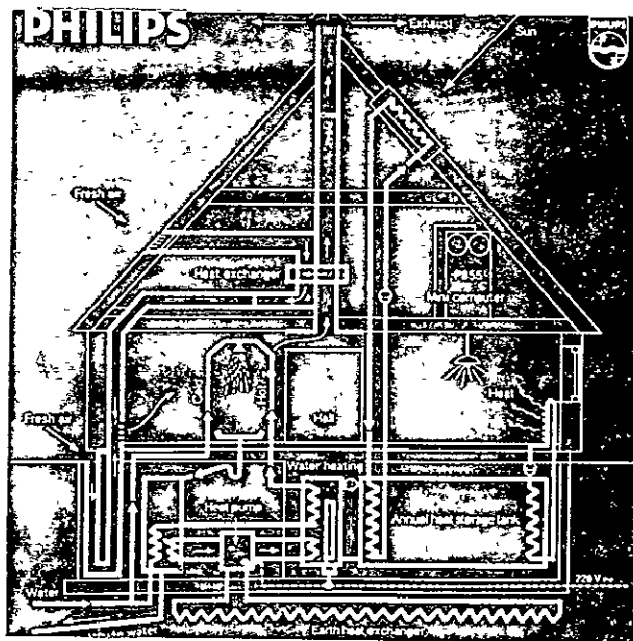


Fig. 2

A picture of this house is shown in Fig. 1. An evacuated-collector area of  $20 \text{ m}^2$  is installed in the roof of this house,

which has a ground-floor living area of 120 m<sup>2</sup>.

Fig. 2 shows a cross-section of the house and the measures investigated for reducing the energy demand. In addition to extraordinary thermal insulation of the walls, improved windows, controlled ventilation, and waste heat recovery from exhaust and wastewater, a heat pump and the solar cycle are being investigated.

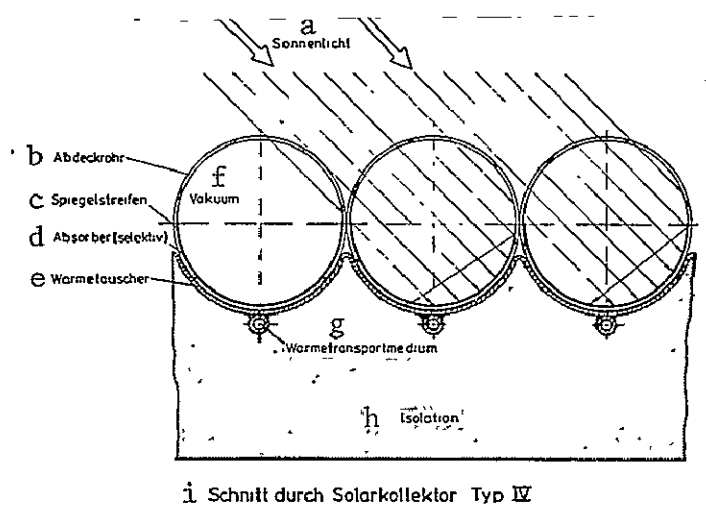


Fig. 3 shows a solar collector developed at the Philips research laboratory in Aachen. It is distinguished by its simplicity and high efficiency. A selective absorber surface developed at the same laboratory is applied to the bottom of an evacuated tube. The tubes are mounted on a heat exchanger and thus represent "solar shingles."

Fig. 3

Key: a - Sunlight; b - Cover tube; c - Reflecting strip; d - Absorber (selective); e - Heat exchanger; f - Vacuum; g - Heat transfer medium; h - Insulation; i - Section through solar collector type IV.

The companies Dornier and Rheinisch-Westfälisches Elektrizitätswerk (RWE) have built an occupied single-family dwelling in Essen, Germany, which is equipped with heat-pipe collectors with an area of 65 m<sup>2</sup>. /17

This house is shown in Fig. 4. The purpose of the house is to test the utilization of solar energy for domestic hot-water and space heating.

The graph in Fig. 5 shows a breakdown of the energy consumed in the house for water and space heating for the year 1976-77. As the graph indicates, about half the energy demand was met by solar energy.

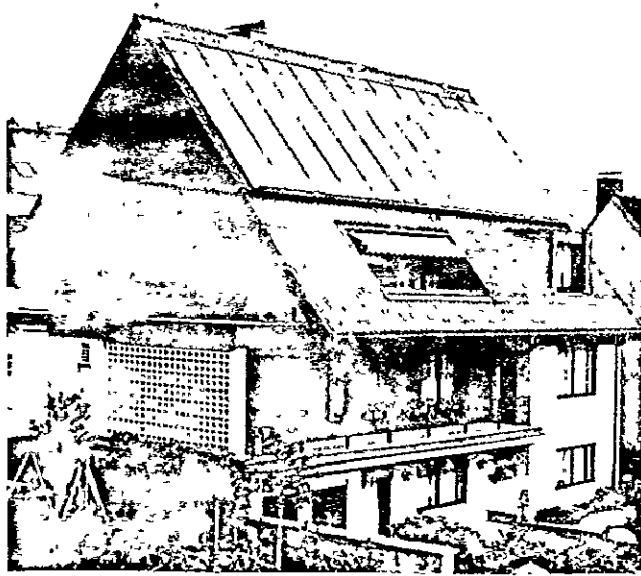


Fig. 4

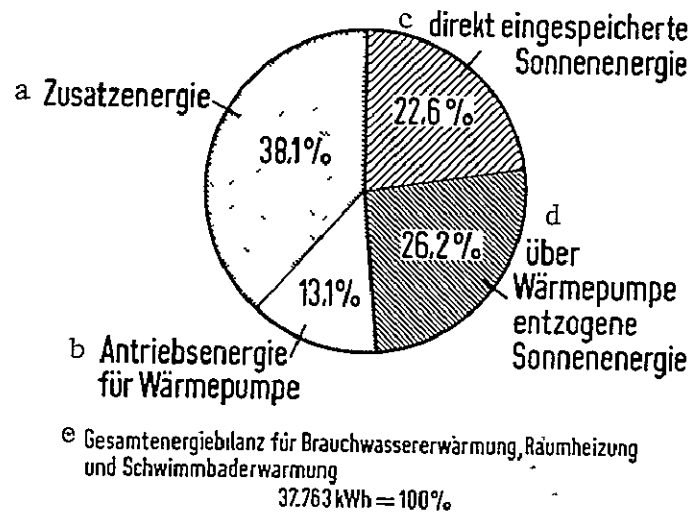


Fig. 5

Key: a - Auxiliary energy; b - Energy for driving heat pump; c - Solar energy directly stored; d - Solar energy extracted by heat pump; e - Breakdown of total energy consumed for water, space and swimming-pool heating (37.763 kWh = 100%).

Fig. 6 shows a view of a Dornier collector like that used in the solar house in Essen.

Fig. 7: A public swimming pool is heated with solar energy in a large-scale test conducted by Rheinisch-Westfälische Elektrizitätswerke. The Figure shows a general view of the complete system. The collector has a total area of 1500 m<sup>2</sup>, making it the largest system in Europe.

Fig. 8: The collectors consist of a non-selective absorber with a glass cover sheet. They were supplied by the Brown-Boveri Co.

**DORNIER**  
Solar Hot Water Generation and Heating -  
Collector Plant mounted on a Flat Roof

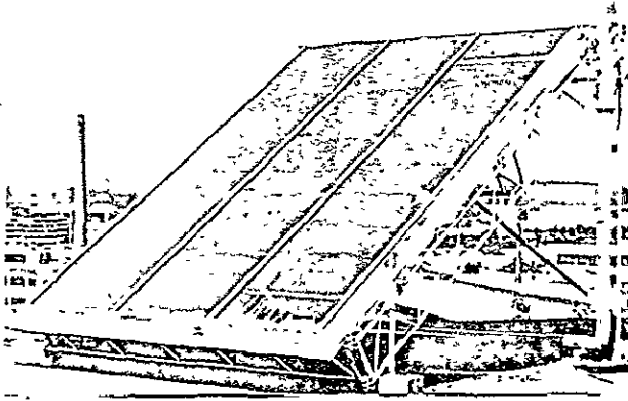


Fig. 6

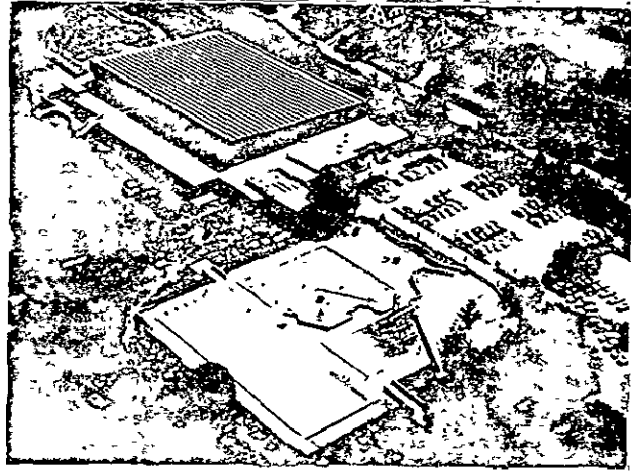


Fig. 7

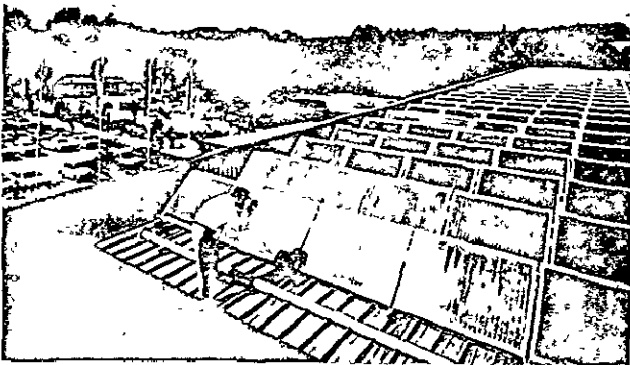


Fig. 8

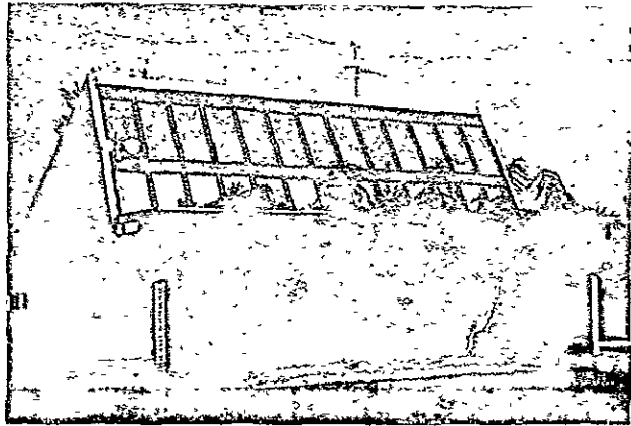


Fig. 9

Fig. 9: The Bosch Co. has built the Junkers Tritherm house, in which three systems -- solar heating, heat-pump heating and fossil-fuel heating -- can be operated in various combinations. The object of these investigations is to determine the optimal combination. The collector surface is comprised of 25 units, each with an area of  $1.6 \text{ m}^2$ , for a total area of  $40 \text{ m}^2$ . The house has a living area of  $174 \text{ m}^2$  and is used by the Bosch Co. for testing and demonstration purposes.

/18

Fig. 10 shows a schematic diagram of the Tritherm system. It can be operated as:

1. a simple solar system,
2. a heat-pump-assisted solar system, and
3. a solar-air-heat pump system.

The object of the investigations is to ascertain the best system configuration under various weather conditions.

Fig. 11: The Siemens Co. has constructed a test facility at its research laboratory in Erlangen, Germany, to investigate

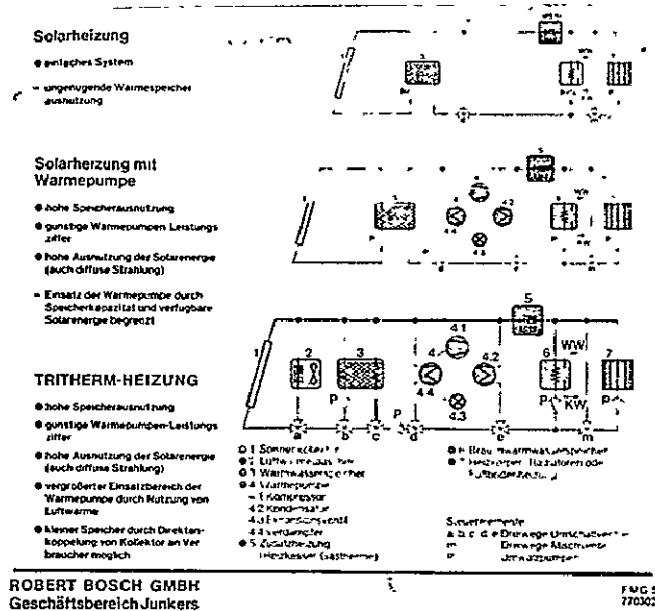
the generation of hot water by a 185-m<sup>2</sup> solar collector. Under favorable insolation conditions, 10 m<sup>3</sup> water is heated to a temperature of 55-60° C.

Fig. 12 shows the 1-cover flat-plate collectors used in the experiments.

Fig. 13 shows the test house of the Rütgers Co. It is an occupied single-family dwelling with a flat roof, on which are mounted 28 collectors (1.5 m<sup>2</sup> each) with various orientations and tilt angles. This arrangement was chosen in order to investigate the feasibility of mounting collectors on facades or roof surfaces. The storage tank has a volume of 20 m<sup>3</sup>, and an 11.4-kW heat pump is installed. The system is used for hot-water, space and swimming-pool heating.

Fig. 14 shows a solar water-heating system with collectors from the Vissmann Co.

/19



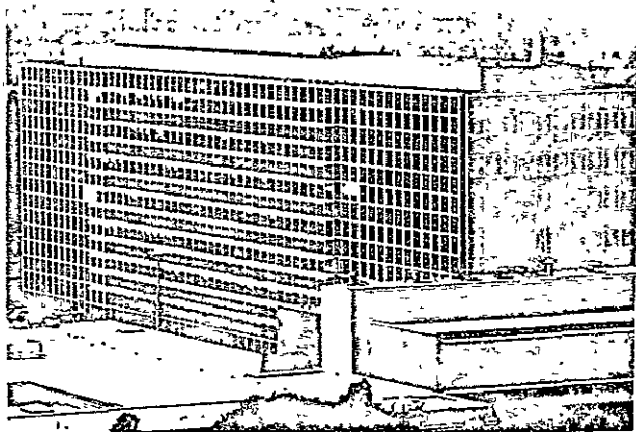


Fig. 11

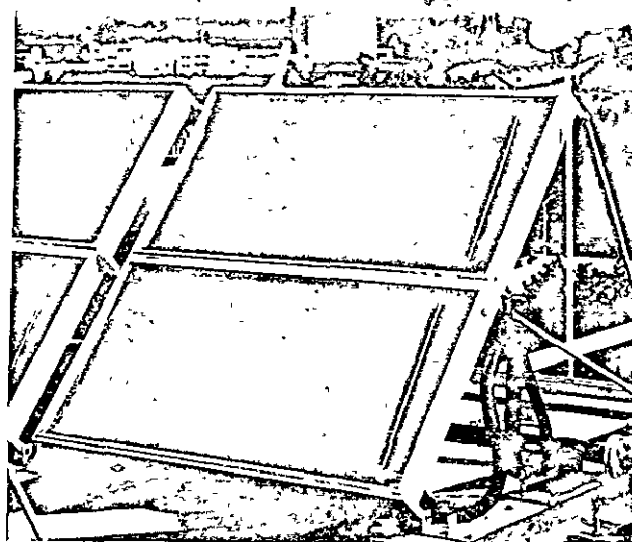


Fig. 12

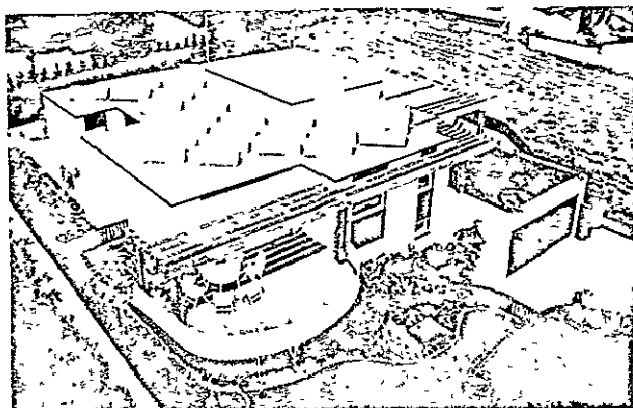


Fig. 13

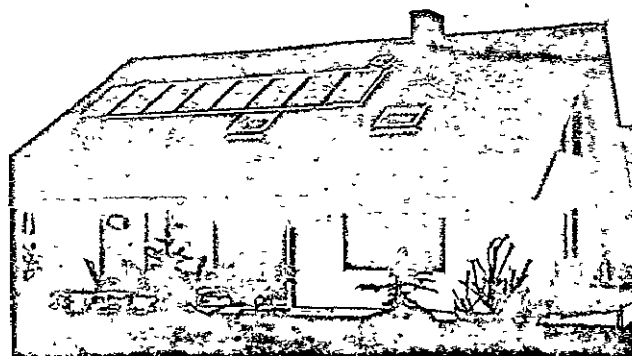


Fig. 14

Fig. 15 and 16: The Stiebel-Eltron Co. has begun the mass production of solar collectors and system components. Fig. 15 shows a system for water and space heating. The collectors used are simple by design and can be integrated into the roof surface (Fig. 16).

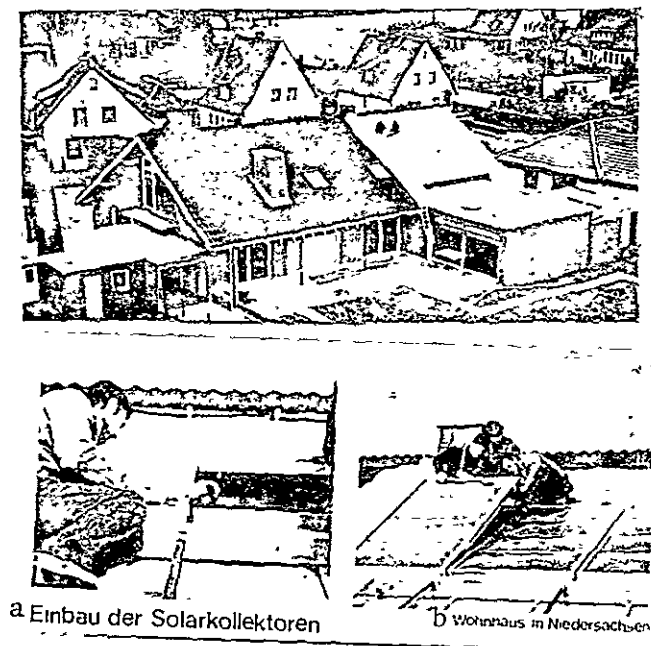


Fig. 15

Key: a - Installation of solar collectors; b - Residence in Lower Saxony, Germany.

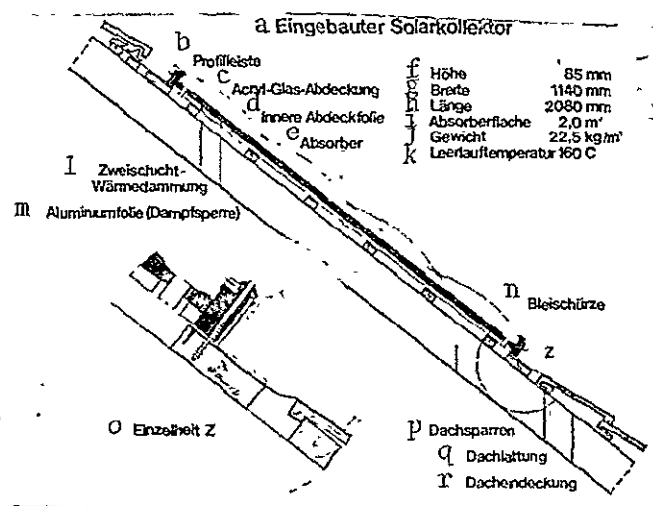


Fig. 16

Key: a - Installed solar collector; b - Spacer bracket; c - Acrylic glass cover; d - Inner cover film; e - Absorber; f - Height; g - Width; h - Length; i - Absorber area; j - Weight; k - Stagnation temperature; l - Two-layer thermal insulation; m - Aluminum foil (vapor seal); n - Lead apron; o - Detail Z; p - Rafter; q - Laths; r - Roofing.

Fig. 17: The Esser Co. has developed special flat-roof collectors which are built into the roofing. A laterally-mounted mirror augments the influx of radiation at lower sun angles.

Fig. 18 shows a solar water-heating system of the MAN Co. which is used to heat shower water at the MAN plant in Nuremberg. The collectors, consisting of a single cover and an aluminum absorber, are encased in a single piece of plastic.

Fig. 19 shows a collector array of the Schäfer Co.

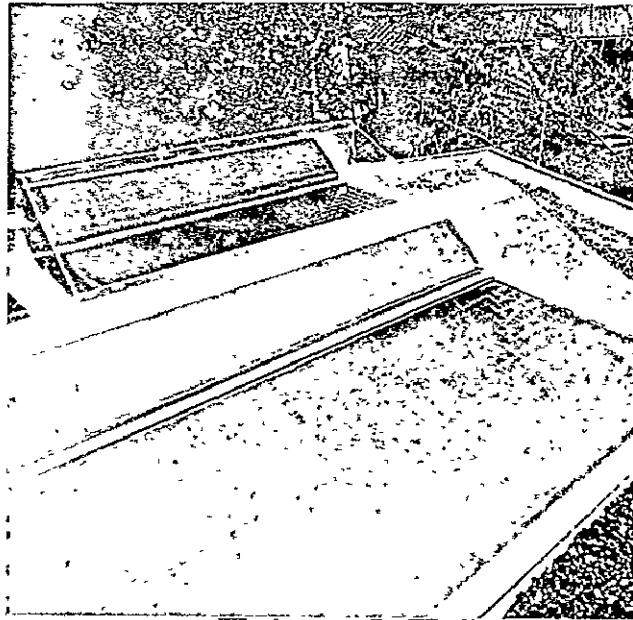


Fig. 17

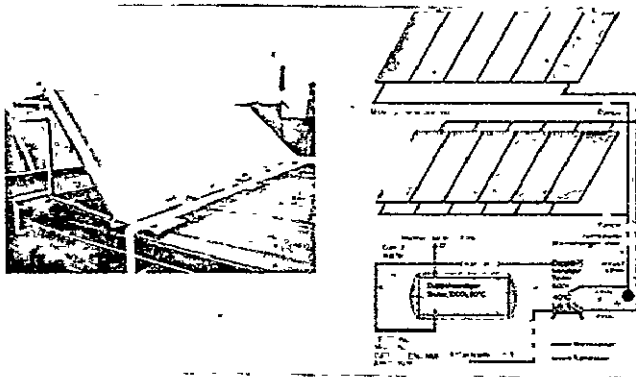


Fig. 18

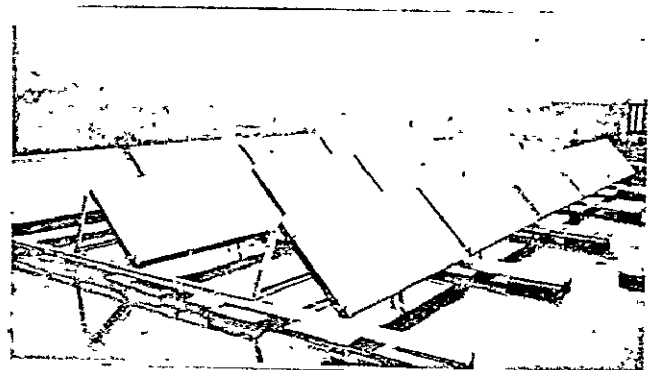


Fig. 19

H. Marhenkel

The problem of utilizing solar energy for cooling is one of the greatest challenges to solar technology.

Here, as in solar heating, the goal is to develop a closed system which is economically feasible.

Progressive solar cooling systems are based on three subsystems:

1. Energy supply: must be regenerative, non-polluting and low-loss.
2. Processes and equipment: must ensure the efficient utilization of available energy with a high degree of safety and reliability.
3. Use: An energy-saving mode of use must be achieved.

The activities described in this paper should be interpreted in terms of these innovative aspects.

If one also considers the fact that solar cooling has not attained great practical importance in Central Europe, the developmental projects outlined here can be considered a contribution to the advancement of solar technology in the Mediterranean region.

First, the firm Messerschmitt-Bölkow-Blohm (MBB) of Munich, Germany, is working on the development of a solar-thermal air-conditioning system for buildings. The project consists of two phases:

Phase I: Construction of a solar-heat driven absorption cooling system by adapting existing elements.

Phase II: Development of a combined heating and cooling system from existing components.

Research is limited to flat-plate collectors and absorption refrigerators. System analysis is accompanied by parallel testing of a 10-kW demonstration plant, in which a collector area of 40 m<sup>2</sup> is connected to a 5-m<sup>3</sup> hot-water storage tank. Of interest is the fact that the cooling compartment, absorption refrigerator, regulator and measuring instruments are all housed in a standard air-freight container. That is, the system is mobile. The collectors, which are integrated with the roof surface, consist of MBB model P-43 2-cover collectors with an absorptance of 0.93 and emittance of 0.13. The refrigerator is an absorption-type unit manufactured by Arkla (U.S.) and distributed in Germany by the Ruckelshausen Co.

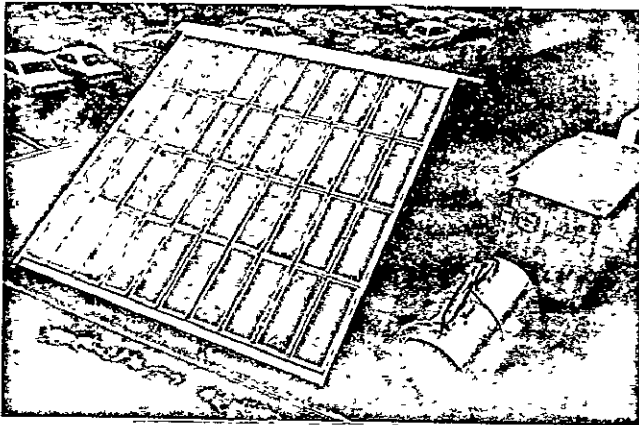


Fig. 1

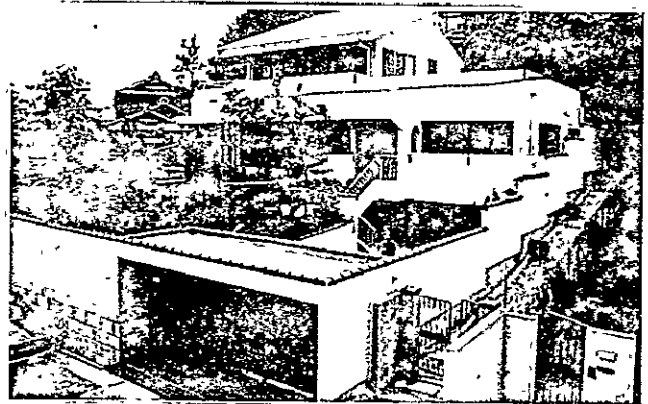


Fig. 2

The collectors operate with absorber plate temperatures up to 130° C, using a synthetic heat-transfer fluid. An operating temperature of 100° C is required. Studies in this complex focus not only on indoor air conditioning, but also on applications in food preservation.

The Dornier System GmbH of Friedrichshafen, Germany, is currently engaged in a project called "Solar Cooling Project Egypt."

This research and development project, financed by the Federal Ministry for Cooperation (BMZ), is being carried out by Dornier System in cooperation with the National Research Center of Egypt. The goals of the project are to demonstrate the feasibility of solar energy utilization for food refrigeration and to institute a transfer of technology to Egypt.

The energy system is designed for cooling about 300 kg of food at refrigerator temperatures (6 to 8° C). The cooling compartment has a volume of 10 m<sup>3</sup>. A cold-lock is built into the system to prevent temperature exchange during loading or unloading of the cooling compartment.

The collector field has an area of 25 m<sup>2</sup> and elevation angle of 30°. It consists of Dornier heat-pipe collectors with double glazing. The collected solar energy is transported directly to the generator of the refrigerator, which is integrated into the collector field.

The refrigerator is developed under subcontract by the firm Linde AG of Cologne, Germany. It is designed as a single-stage, water-cooled absorption unit with an ammonia-water working medium.

The refrigerating capacity is 4 kW at a generator temperature of 90° C. The machine is so designed that approximately 10 kW of cooling energy can be stored in the form of liquid ammonia for cooling at night. In consideration of the high water temperatures in southern countries, the system was designed to accommodate a /21 cooling-water temperature of 30° C.

The project has been underway since April 1, 1976. In March/April, 1978, the system was function-tested at Dornier's testing

grounds in Germany. Afterwards it was shipped to Egypt and set up on the testing grounds of the Solar Energy Laboratory in Cairo.

Since June of 1978, long-term tests have been in progress at that site for the purpose of adapting the system to conditions in Egypt. In addition, Egyptian industry is receiving the technical support necessary for it to manufacture the system itself.

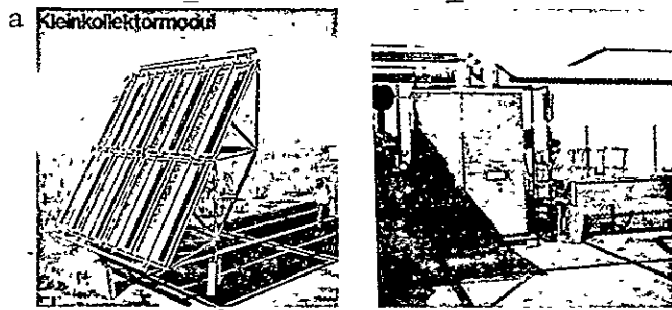


Fig. 3

Key: a - Modular collector.

An entirely different system concept has been introduced by the Department of New Technology of the Augsburg-Nuremberg Machine Factory in Munich.

The picture shows a small modular collector with a collector area of 25 m<sup>2</sup> for cooling and air conditioning. It forms the basic component of an autarkic solar cooling system by means of power/cold coupling.

Concentrating collectors heat the working medium to a temperature of 200-250° C, which drives an expansion machine. The mechanical and electrical energy are used to power an absorption cooling system (pumps, blowers, controls).

The waste heat is used at a temperature of about 110° C to drive the absorption system for cooling or air conditioning.

The solar cooling systems of the Brown Boveri & Cie. AG of Mannheim, Germany, contain the BBC Yazaki absorption refrigerator as their central system component. Here are some examples of system designs:

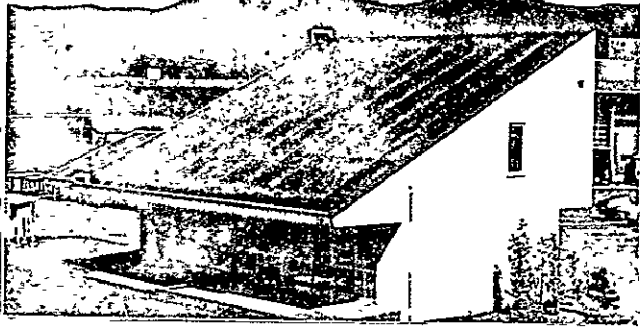


Fig. 4

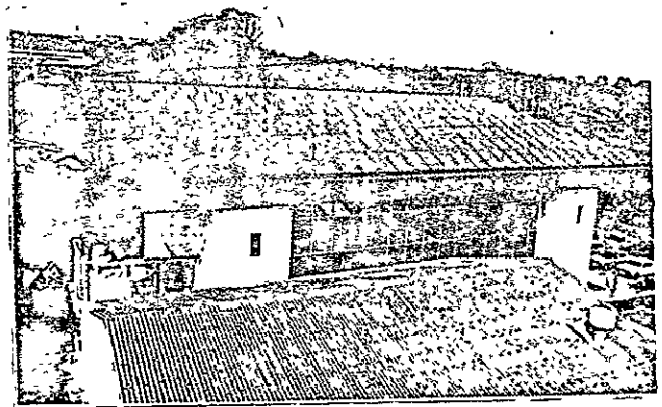


Fig. 5

Fig. 4 shows an experimental house which began solar operation in July of 1974.

Collector area:	142 m <sup>2</sup>
Hot-water storage capacity:	5 m <sup>3</sup>
Refrigeration unit:	1.3 RT = 4.5 kW

Fig. 5 shows a meeting hall equipped in April, 1976, with a combined solar heating and cooling system.

Collector area:	716 m <sup>2</sup>
Hot-water storage capacity:	20 m <sup>3</sup>
Refrigeration unit:	22.5 RT = 78 kW

Fig. 6 shows the cooling system which began operation in a private residence in February, 1977.

Collector area:	61 m <sup>2</sup>
Hot-water storage capacity:	3 m <sup>3</sup>
Refrigeration unit:	2 RT = 7 kW

This system corresponds roughly in design to that which was

installed in the BBC solar house in Heidelberg in 1976 and which is presently being installed in another system in Spain.

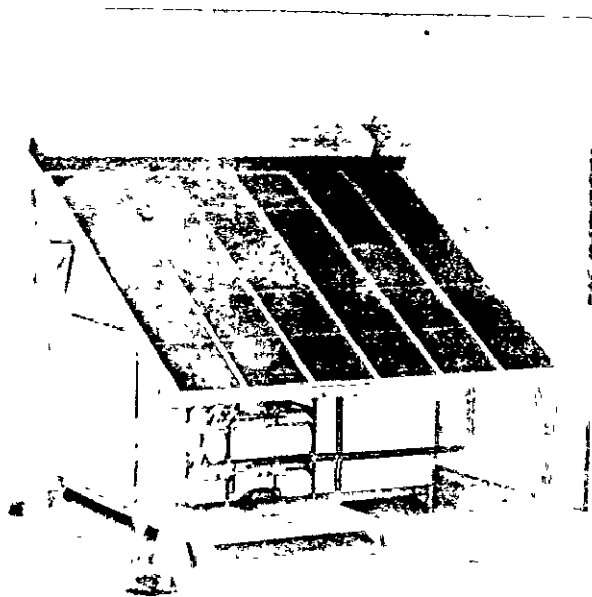


Fig. 6

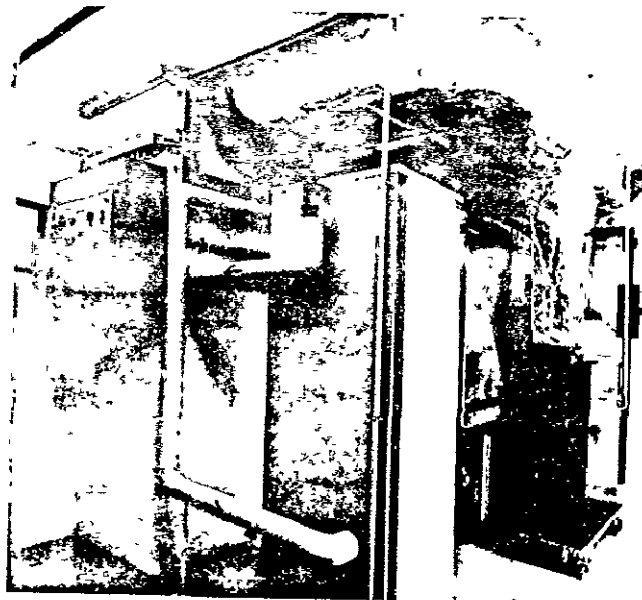


Fig. 7

Fig. 7 shows the BBC Yazaki absorption-type refrigeration unit in the BBC solar house.

One object was also to test the unit under unfavorable insolation conditions in Germany. It was confirmed that the unit functions satisfactorily at a solar-heated water temperature of 75° C.

As experience has shown, the following types of flat-plate collectors can be employed:

/22

Single-glazed, non-selective  
Double-glazed, non-selective.

In general, however, the latter type is preferred.

It has been found that the installation of a cold-water storage as a supplement to hot-water compensating storage is advantageous for day- and nighttime operation. The combination of cooling and low-temperature heating is also becoming increasingly prominent as a system requirement.

Recalling the challenge mentioned at the start of this paper, it would be well for us to take a greater joint interest in the concept of solar cooling.

A. Ziemer

The utilization of solar energy for seawater desalination represents one of the earliest technical applications of solar energy in general. Long before the oil crisis and the consequent interest in the use of regenerative primary energy sources focused serious interest on the solar energy alternative, the solar treatment of seawater and brackish water was already one of the few technical, or rather semi-technical, applications of solar energy.

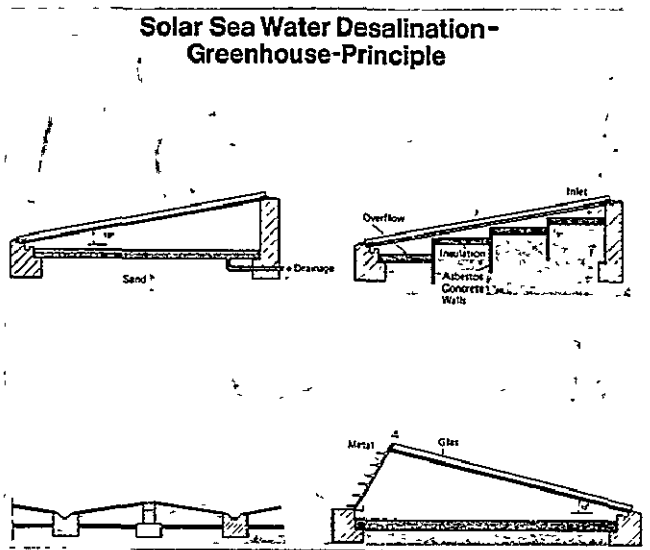


Fig. 1

The principle on which this application is based is the so-called greenhouse process, which involves the simple evaporation of seawater in covered basins followed by its condensation on the cover sheet. Fig. 1 shows

various designs for such simple greenhouse systems. One advantage of systems of this type is that they are simple to manufacture by hand and require no special control measures. Their disadvantages are that their handcrafted construction prohibits any efficiency considerations, they occupy a relatively large area, and their capacity limits are such that they are suited chiefly for the small-scale production of fresh water. Moreover, these systems are extremely repair- and maintenance-intensive. One need only consider the proneness of moist wood to rotting, and the fact that breakage of the glass cover will render the system practically useless due

to resulting vapor losses. Besides this, the actual manufacturing costs of such systems are quite high if we disregard their hand-crafted construction and subject them to industrial cost analysis. Nevertheless, these systems utilize solar energy and illustrate the specific advantages of solar energy in seawater desalination: It is suited primarily for small, isolated consumers, for whom the problem of procuring drinking water ranks above strict economic considerations.

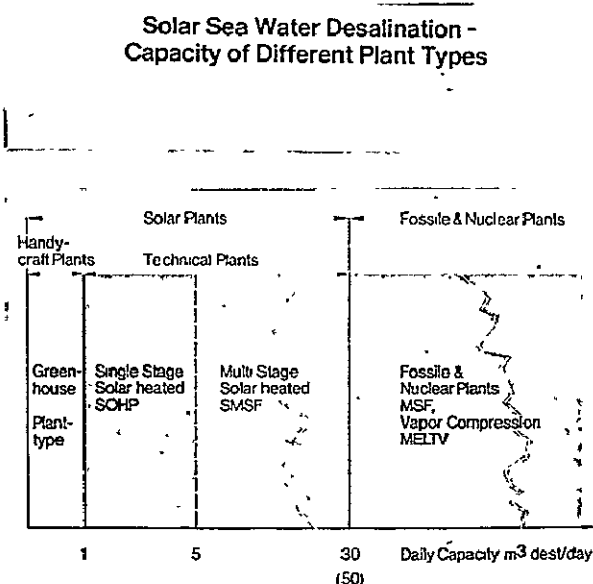


Fig. 2

I have made this digression to the subject of hand-made greenhouse systems intentionally in order to point out the boundary conditions which must be taken into account in considerations of solar energy utilization for seawater desalination. Fig. 2 shows one result of these considerations with regard to possible system capacities. It can be seen that the aforementioned greenhouse systems have their place up to an output of 1 m³ distillate/day. Industrial plants are senseless in this range, for we are dealing

with consumers who rank the problem of supply and the possibility of self-help far above efficiency considerations. In the range above 30 to 50 m³ distillate/day (the limits indicated are somewhat flexible), we enter the range of the fossil- and even nuclear-fueled systems available on the market. In the intermediate range, i.e., between 1 and 30 (50) m³ distillate/day, is the area of solar plant application. We can now specify the type of consumer to whom such systems are directed: Those who are in isolated locations, with limited access to electrical or fossil energy, and with a daily

demand commensurate with the indicated upper limit for solar plants. We are speaking specifically of drinking water for:

- village communities
- schools, kindergartens
- hospitals, first-aid stations
- hotels
- coastal stations, police stations.

But not:

- water for agricultural use
- water for industrial use.

Present member firms of the BSE have been engaged in developmental work in this range of capacities for some time -- many since the early 1970s and thus long before the so-called oil crisis. The results of this work are solar seawater and brackish-water treatment plants which operate by known desalination processes such as open, single-stage desalination and multi-stage flash evaporation. The single-stage systems can cover roughly the capacity range up to 5 m<sup>3</sup> distillate/day, while the multi-stage systems have outputs up to 30 (50) m<sup>3</sup> distillate/day (see Fig. 2). /2/

I would like next to discuss the status of developmental work and some basic performance data, taking as examples certain systems which are now completed or are undergoing completion.

Fig. 3 shows the functional diagram of a single-stage system manufactured by Dornier, which operates by evaporation in an open pan. The incident solar energy is captured by flat-plate collectors and transported by heat pipes to the heat exchanger. Here the brine is evaporated, and the vapor condenses on the brine preheat surfaces. The condensate thus obtained is collected in a trough and channeled into the drinking-water container. Fig. 4 shows the schematic diagram of a complete desalination plant with collecting station, seawater storage, modular collector array and piping.

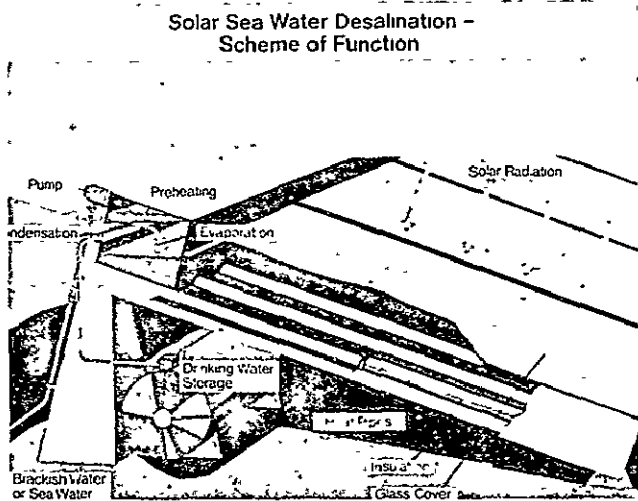


Fig. 3

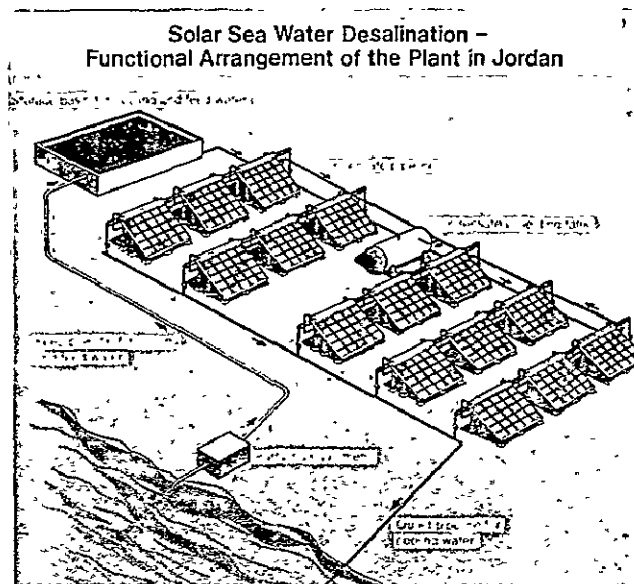


Fig. 4

The performance data for such plants are as follows:

- Desalination capacity of completed plants:  $5 \text{ l/m}^2$  collector area
- Desalination capacity of new experimental plants with improved heat exchanger: up to  $12 \text{ l/m}^2$  collector area
- Brine temperature: approximately  $70-95^\circ \text{ C}$ .

Fig. 5 shows a plant in Aquaba, Jordan, which was designed according to this principle. The plant has a total capacity of  $200 \text{ l}$  distillate/hr and a cooling-water demand of  $3 \text{ m}^3/\text{hr}$ . Fig. 6 shows the heat exchanger with its plastic film lining. This film facilitates the removal of incrustations.

Fig. 7 shows the functional diagram of a solar-heated multi-stage flash-evaporation plant, also manufactured by Dornier. Plants of this type have capacities up to  $50 \text{ m}^3$  distillate/day

Solar Sea Water Desalination -  
Collector Field of the Plant in Jordan

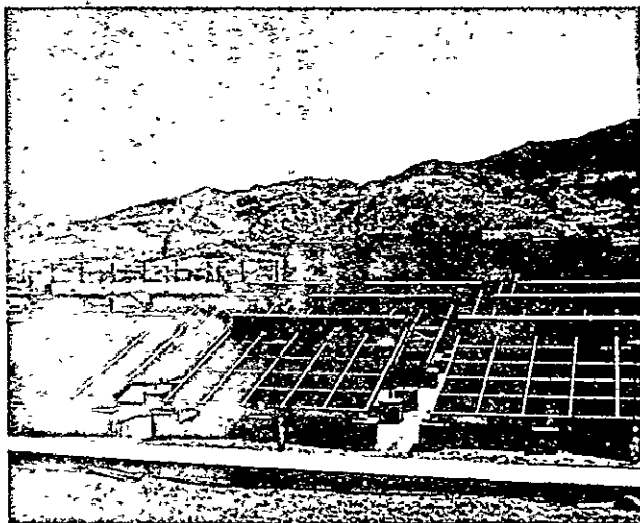


Fig. 5

Solar Sea Water Desalination -  
Distillation Basin of a Collector Module

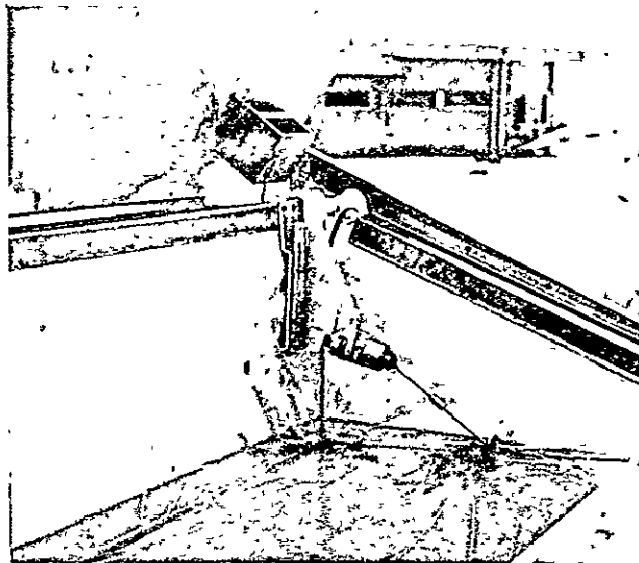


Fig. 6

with a desalination capacity up to 20 l distillate/m<sup>2</sup> collector area. These plants thus close the capacity gap between the single-stage plants and the fossil-fueled plants on the market. They are particularly well suited for supplying village communities, hotels and hospitals. The collector field at the left of the Figure is divided into flat-plate collectors for preheating and for utilizing diffuse solar radiation, and concentrating collectors for generating the necessary process temperatures of approximately 120° C. These are connected to a hot-water storage tank and a heat exchanger. The multiple stages of the system are supplied with heating energy via the heat exchanger. The hot-water storage tank enables 24-hour operation by acting as a buffer for sunless periods. The energy for supplying and removing the brine as well as for generating a vacuum must be provided by fossil or electrical means, resulting in an overall system energy demand of 85% solar and 15% conventional.

Fig. 8 shows the functional layout of an experimental plant

based on this process. This plant in La Paz, Baja California, will become operation in mid-1979. .

Solar Sea Water Desalination -  
Scheme of Function of a Multistage Plant

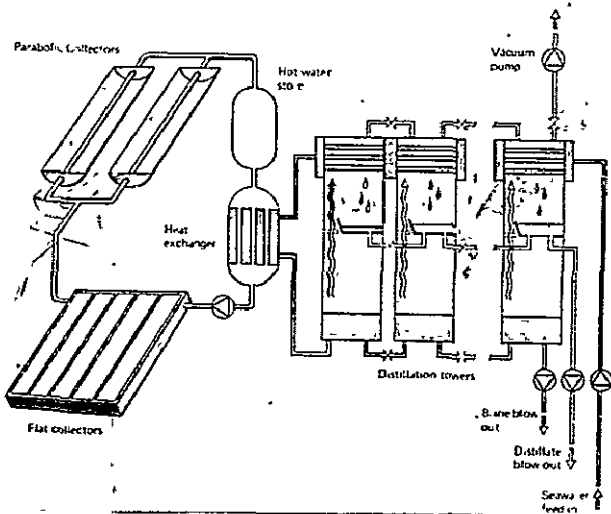


Fig. 7

Solar Sea Water Desalination -  
Functional Arrangement of the Plant in Mexico

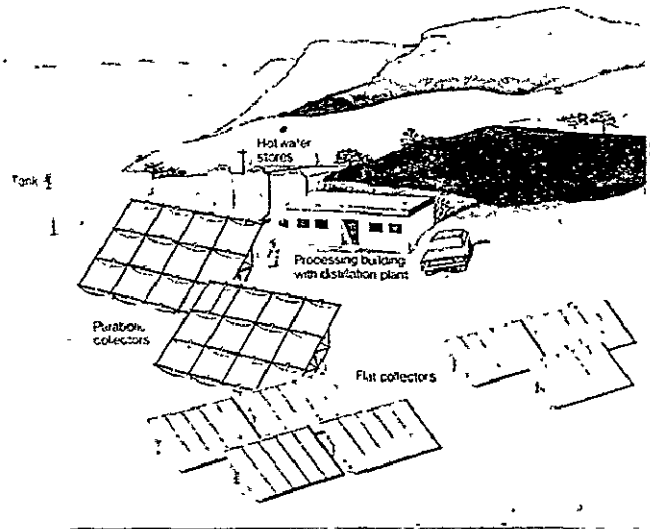


Fig. 8

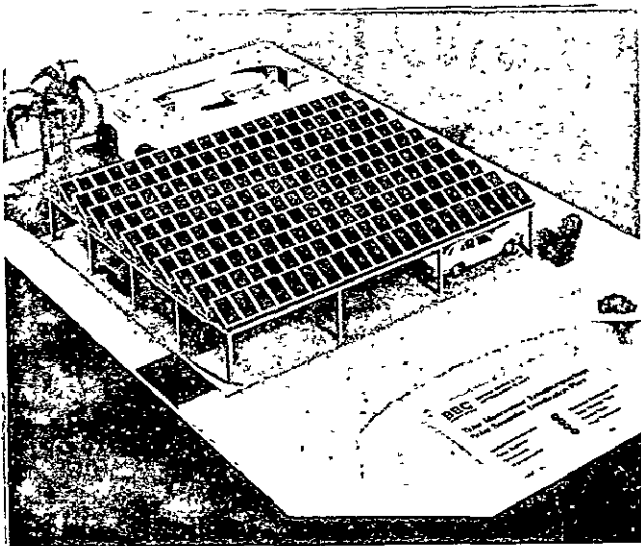


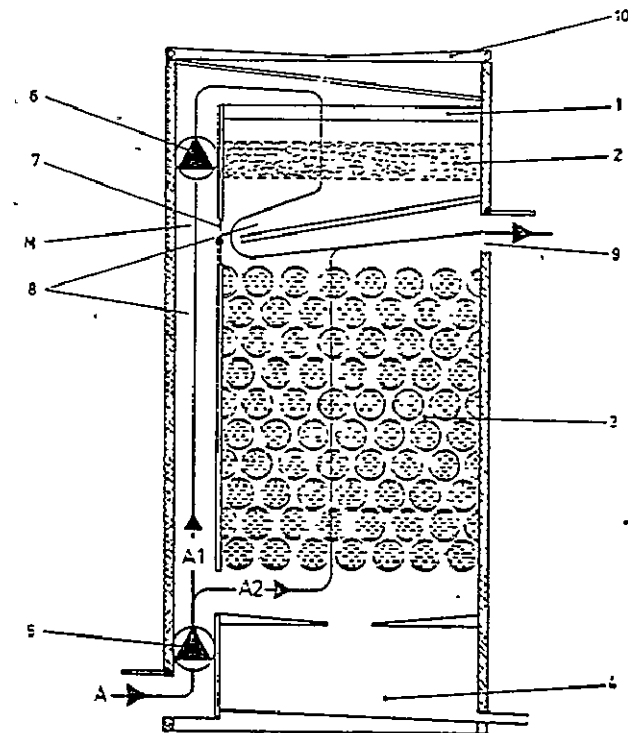
Fig. 9

stages are rectangular in design, are fabricated from rustproof

Fig. 9 shows a model of a standardized plant manufactured by BBC. This plant also operates by the multi-stage flash-evaporation principle. An effective collector area of about  $230 \text{ m}^2$  provides the heat for driving a 5-stage evaporation system. At an expected production rate of  $10 \text{ l distillate/day per m}^2$ , the plant has a capacity of  $2 \text{ m}^3/\text{day}$ . The necessary vacuum is produced by seawater ejectors. The five evaporation

steel, and are welded together to form one unit.

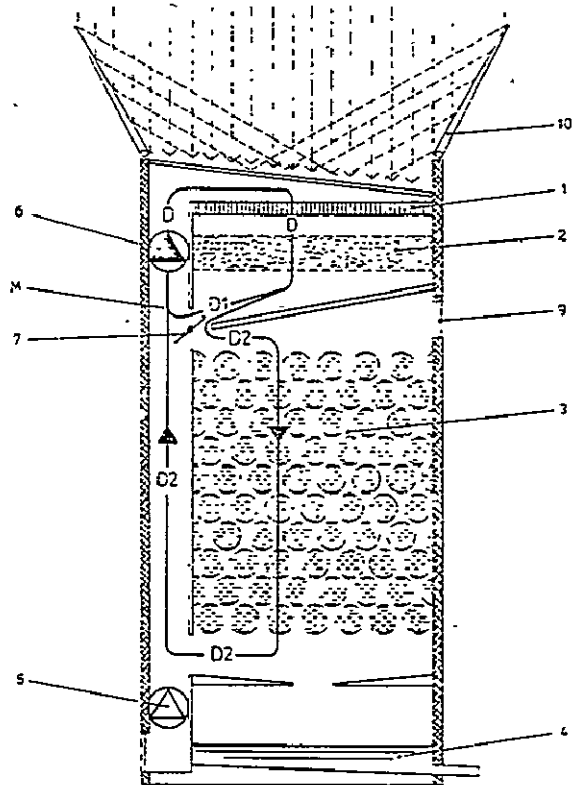
To digress somewhat from the subject of seawater desalination, I would like to discuss a developmental project of the MAN Co. which also deals with the production of drinking water with the aid of solar energy. In this process, however, drinking water is produced by the absorption and condensation of moisture from the air.



SOLAR WATER RECOVERY CROSS SECTION  
ADSORPTION AND COOLING PHASE

- |                    |                       |
|--------------------|-----------------------|
| 1. Solar collector | 7. Valver             |
| 2. Absorber        | 8 Air ducts           |
| 3. Condenser       | 9. Air exit           |
| 4. Water chamber   | 10. Mirror            |
| 5. + 6. Blowers    | A, A1, A2 Air streams |

Fig. 10



SOLAR WATER RECOVERY PLANT CROSS SECTION  
CONVECTION HEATING AND BY-PASS CONDENSATION

- |                     |                       |
|---------------------|-----------------------|
| 1. Solar collectors | 5. + 6. Valve         |
| 2. Absorber         | 9 Air exit            |
| 3. Condenser        | 10. Mirrors           |
| 4. Water chamber    | D, D1, D2 Air streams |

Fig. 11

The principle of the process is illustrated in Fig. 10 and 11. Fig. 10 shows the absorption and cooling phase. Cold night air is forced by blowers through a heat exchanger (e.g., rocks) and

through a silica gel absorber. In the process, the absorber becomes charged with moisture from the air. At a suitable atmospheric humidity, 100 g of silica gel can store up to 30 g water. Fig. 11 shows the water recovery phase of the system, which operates by solar energy during the day.

An enclosed air volume is circulated through the system by a pump. It is first heated to about 100° C by the solar collectors at the top of the Figure. It then absorbs the moisture from the silica gel particles and passes to the heat exchanger for cooling. There the absorbed moisture is condensed out. Fig. 12 shows an

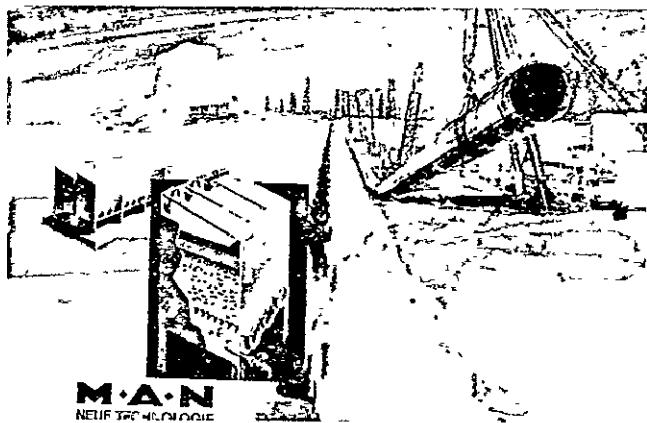


Fig. 12

architect's drawing of the use of such plants in arid regions. It should be noted that misconceptions often exist with regard to the absolute humidity of the air -- the volume of water actually stored in the air -- in arid regions. The absolute humidity at In Salah in the Sahara is almost equal to that in Paris. Thus, the air in arid regions contains a considerable quantity of water which can be condensed out. /26

As mentioned, the process just described is still in the developmental stage. Thus, performance data on these systems can be obtained only on the basis of preliminary theoretical investigations. These indicate that approximately 10 tons of silica gel and 150 m<sup>2</sup> collector area are required for each ton of water produced. The blowers can be oil-driven or, if conditions are suitable, may be powered by wind energy.

J. E. Feustel

Introduction

Besides the utilization of solar energy in the low temperature range (water heating, for example), solar-thermal applications in the intermediate and high temperatures ranges are also of interest, especially with regard to the generation of electric power. The use of solar-thermal power generating plants appears particularly promising in regions with high direct insolation, and thus in the

zone between approximately  $40^{\circ}$  north and south latitude. In the countries of Southern Europe, such plants can make a substantial long-term contribution to electric power generation, for up to 3000 hours of direct sunshine per year are obtained in these areas (Fig. 1). Beyond these applications in the European sphere, moreover, there is a considerable export potential, particularly to developing nations. These applications of solar energy have long been recognized in the Federal Republic of Germany and have been encouraged and de-

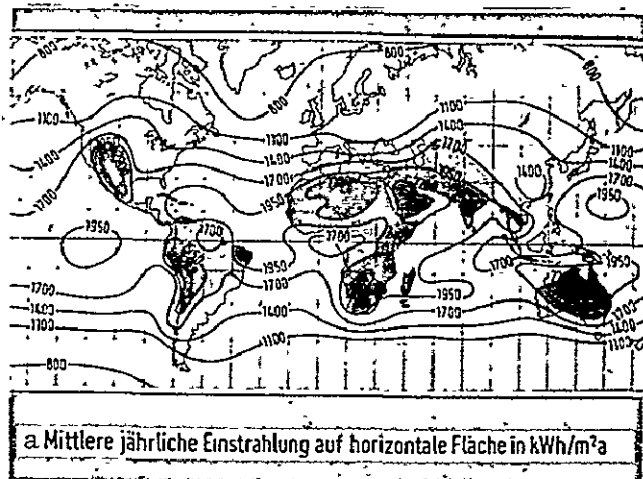


Fig. 1

Key: a - Mean annual insolation on horizontal surface in  $\text{kWh/m}^2\text{a}$ .

veloped in the wide range of solar projects.

Before discussing the current status of developmental work in the Federal Republic, I would like to present briefly the main

technical concepts which appear to hold particular promise with regard to solar-thermal power generation. One is the solar farm concept, the other is the solar tower approach.

Whereas the solar farm employs arrays of collectors which simultaneously concentrate the sunlight and convert it to thermal energy, the solar tower separates the functions of light collection and energy conversion. In this case the light is collected by an array of mirrors, but the energy is converted to heat in a centrally-located absorber (Fig. 2).

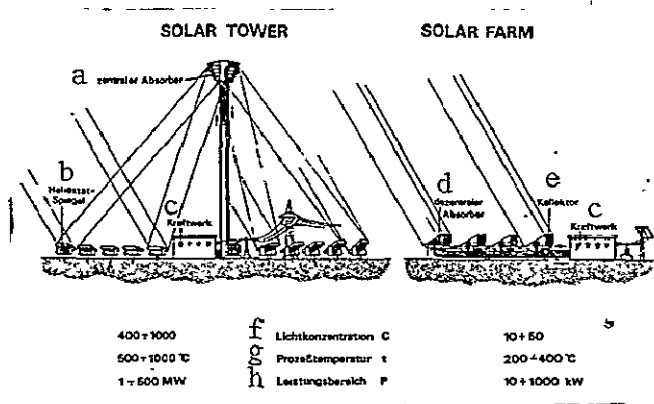


Fig. 2

Key: a - Central absorber; b - Heliostat mirrors; c - Power plant; d - Decentralized absorber; e - Collector; f - Light concentration; g - Process temperature; h - Capacity range.

One consequence of this basic difference is that solar farm systems operate primarily in the intermediate temperature range at capacities of about 10 kW to a maximum of 1000 kW. Solar tower systems, on the other hand, function best in the high temperature range and are suited for capacities from about 1 MW up to several 100 MW. Thus, each concept is supplementary to the other and should not be considered competitive: Solar farm systems are better suited for decentralized power generation by smaller plants, while solar

tower systems are more suitable as power plants in the large-capacity range. The difference in terms of range of application and temperature level implies yet another difference with regard to the technology which must be employed. While the technological costs for solar farm systems are considered to be imposing, those for solar tower systems are extraordinarily high, as in all advanced power plant concepts.

## Development of Solar Farm Systems ..

I would now like to present a brief survey of development work on solar farm systems.

Several different concepts for solar farm systems are currently being pursued in the Federal Republic. The main distinguishing features of these systems are the types of collectors employed on the one hand, and the working media and thermal engines on the other. With regard to collector types, a distinction is made between:

- systems with flat-plate collectors, such as those developed by MBB and AEG
- hybrid systems employing flat-plate collectors and concentrating collectors, like those developed by Dornier
- systems based exclusively on concentrating collectors, such as those developed by M.A.N., Dornier and MBB.

With regard to working media, both water and thermal oils are used in the collector cycle, while organic compounds such as freons, toluene or even conventional steam are used in the energy-conversion cycle, depending on the temperature level. The thermo-mechanical energy converter may be a piston machine, turbine or helical expansion engine. Let us now look at some typical solar farm developments which illustrate the broad range of plant capacities.

Under contract from the Federal Ministry for Research and Technology, the MBB Co. has developed a solar farm plant with flat-plate collectors and a rated capacity of 10 kW. This prototype /28 plant is intended for electric power generation in remote rural areas without an adequate infrastructure. Based on the use of

flat-plate collectors, a maximum process temperature of approximately  $95^{\circ}\text{C}$  is achieved, with a total attainable efficiency of about 2%. The thermodynamic energy converter consists of a helical expansion engine with freon R 114 as the working medium. Between the engine and generator is a mechanical reduction gear. It was decided to use only tested, commercially-available components in this plant. The plant was first integrated and pre-tested in Munich, Germany, and is presently being subjected to a long-term testing program in Madras in cooperation with the Indian Firm BHEL (Fig. 3).

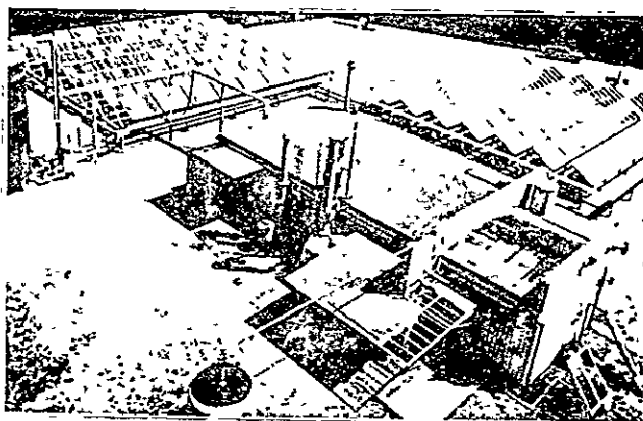


Fig. 3

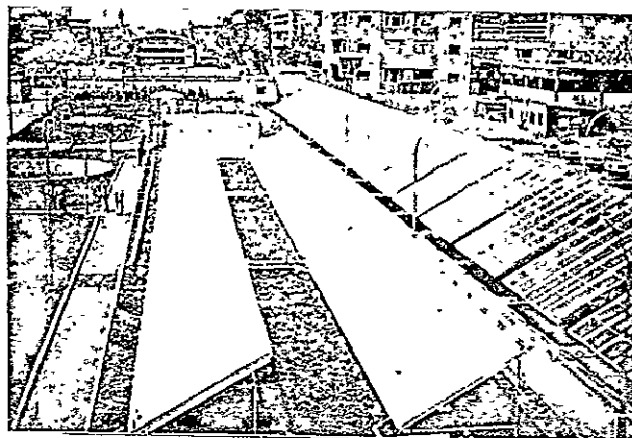


Fig. 4

The Dornier System Co. is also developing a 10-kW solar farm plant under contract from the Federal Research Ministry. It has already begun operation in Cairo (Fig. 4) and is being tested there jointly with the National Research Center of Egypt. The plant employs a hybrid collector array with a flat-plate collector area of  $400\text{ m}^2$  and a concentrating-collector area of  $200\text{ m}^2$ ; in this way the maximum process temperature can be increased to  $130^{\circ}\text{C}$  and, with it, the efficiency of the system. Instead of a helical expander, a newly-developed freon-operated, high-speed turbo-generator is employed. An encapsulated, maintenance-free unit is created by this arrangement. The high-frequency alternating

current is rectified and inverted to yield a direct current or a 50-Hz alternating current (Fig. 5).

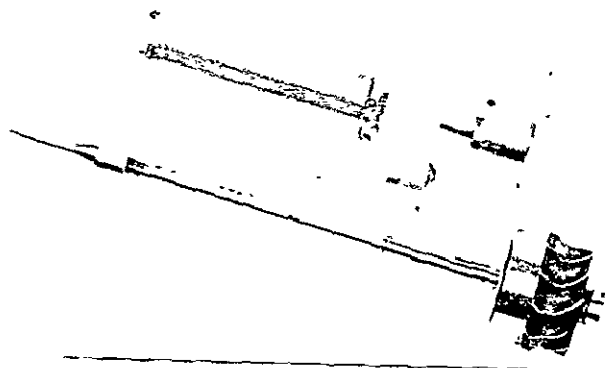


Fig. 5

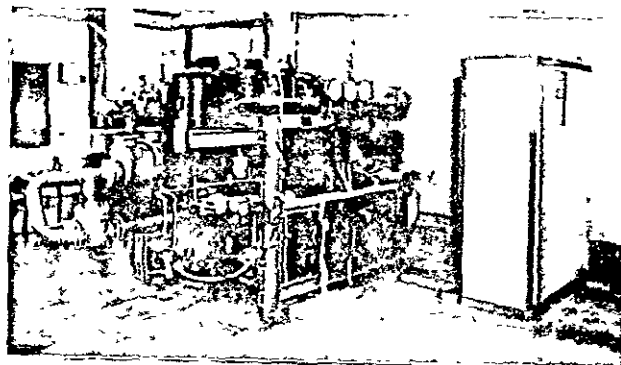


Fig. 6

Another plant for temperature levels in the 100° C range is being developed by the firm AEG-Telefunken, which has given particular attention to development of the electrical section of the plant. The 10-kW plant also operates with freon 114 in the engine cycle, which employs a helical expander. During the first phase of the project, the thermal engine, plant controls and generator were simulated in the laboratory; the solar collectors were simulated by an electrically-powered continuous flow heater (Fig. 6). The field-testing of the plant is being conducted jointly with the Democritos Nuclear Research Center in Greece, which is providing the collector field, heat storage and infrastructure. The collector field (Fig. 7) consists of 2-cover flat-plate collectors, which heat the water to about 95° C. The plant was put into operation in the summer of 1978 following testing of the individual systems.

Besides these plant types, which operate at a relatively low 29 temperature level, particular interest is focused on designs which employ a higher range of temperatures. This requires the use of

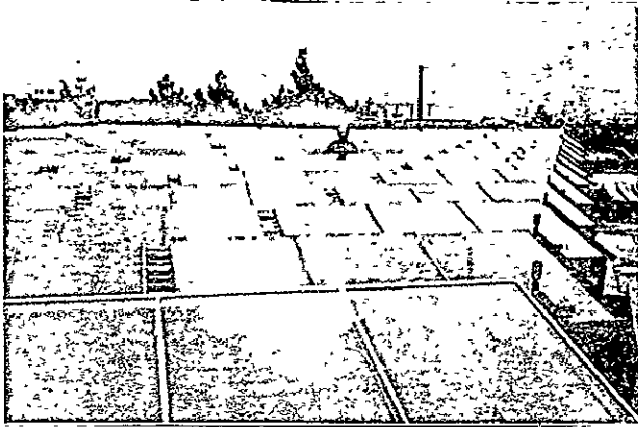


Fig. 7

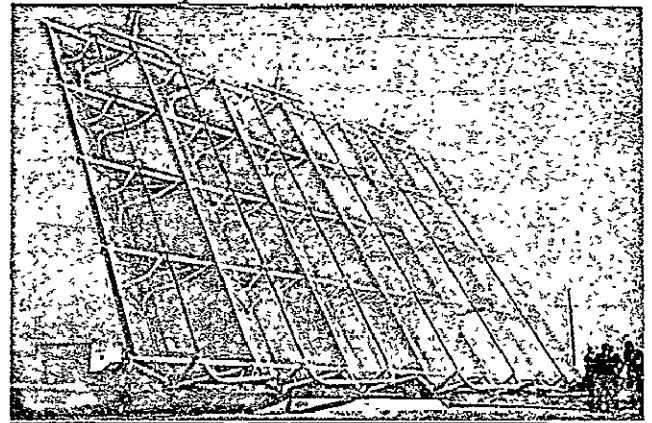


Fig. 8

concentrating collectors. The M.A.N. Co. has for several years been engaged in the development of systems with cylindrical parabolic collectors which attain temperatures of approximately  $300^{\circ}\text{C}$  with good efficiency. Such systems can provide plant efficiencies of about 10% for power generation alone, and about 30% for plants which produce both electric power and heat (total energy systems) for desalination, refrigeration, air conditioning, etc. Extensive tests with various cylindrical parabolic collectors and energy conversion systems which employ steam exclusively have been conducted within the framework of various antional and international development programs.

One of the first collector systems (Fig. 8) was put into operation in Madrid in July, 1978, in cooperation with the Spanish industrial firm Auxini. Advanced, high-performance, fully-tracking collector modules (Fig. 9) are being supplied to Southern Spain for several solar farm plants, including the 500-kW plant of the International Energy Agency (IEA). The collector system employs high-performance hot-formed glass mirrors, which were qualified by the firm Flachglas in extensive developmental studies. The selection of optimal energy conversion systems is as important as the collector. M.A.N. is developing 2-stage steam-operated

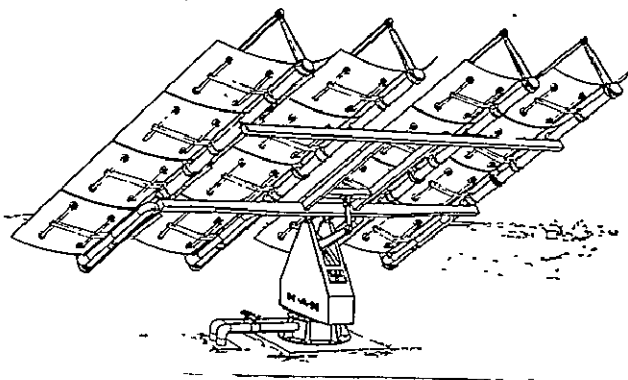


Fig. 9

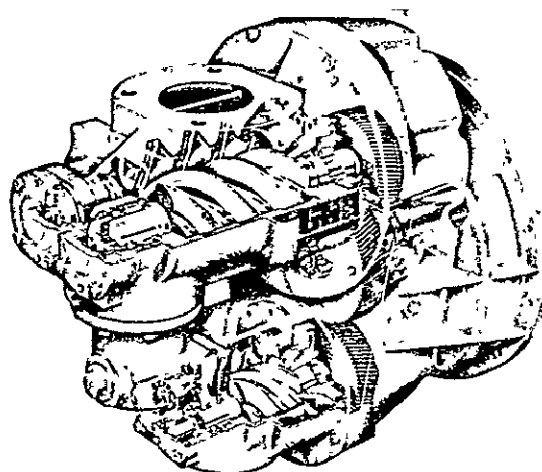


Fig. 10

helical expanders (Fig. 10) for capacities of 50-500 kW under contract from the Federal Research Ministry. These engines are characterized by high efficiency, rugged construction and simplicity of operation.

Besides cylindrical parabolic collectors, highly-concentrating circular parabolic collectors can also be used in solar farm systems. Designs for both intermediate- and high-temperature applications are being investigated by German industry. The MBB Co. has designed a solar farm system which employs circular parabolic collectors with concentration factors of 200 and process temperatures of 350° C and higher, using mirrors about 3 m in diameter. For autonomous power generation in remote sun-rich areas, MBB is developing a solar power station with a rated capacity of 100 kW under contract from the government of Kuwait (Fig. 11). The M.A.N. Co. is developing designs with mirror diameters in excess of 10 m (Fig. 12 shows a prototype with a 5-meter mirror). These paraboloid mirrors can achieve maximum temperatures of about 800° C. The energy converter (e.g., gas turbine or Stirling engine) is located at the focal point or in its immediate vicinity in order to avoid heat losses due to extensive pipe lengths. These systems can be

operated as individual plants with capacities of about 20 to 25 kW.



Fig. 11

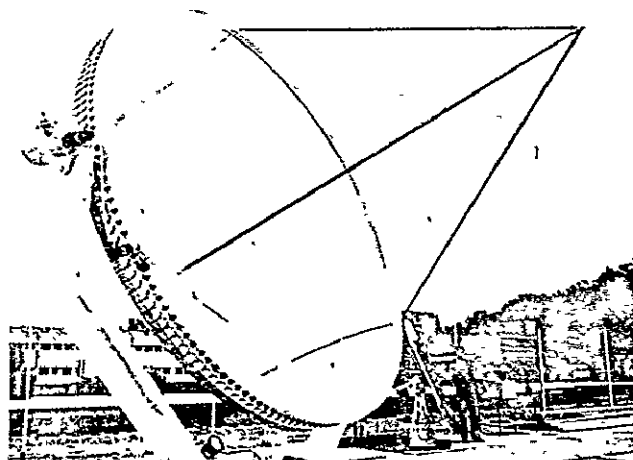


Fig. 12

### Development of Solar Tower Systems

/30

Besides the extensive developmental work being devoted to various solar farm designs in the Federal Republic, developmental projects are also underway on highly-concentrating solar tower systems. While possibilities are limited in terms of the mirror design in such systems, ranging from plane to slightly curved, a large variety of possibilities exist with regard to the design of the central absorber, working media and energy converters. The determining factors are the selected temperature level and the working medium. Solar tower systems are suitable in the intermediate term for producing temperatures between 500° and 800° C, although it appears in the long term that temperatures in excess of 1000° C can be generated for the production of hydrogen, for example. Water, air, helium or sodium can be used as working media in the primary cycle, while steam, air or helium are suitable for use in the energy conversion cycle, depending on the temperature. Conventional steam turbines, gas turbines (open system) or advanced gas turbines with helium or air (closed system) make suitable thermomechanical energy converters. A wide

range of energy converters, including conventional steam turbines as well as air or helium gas turbines, are available to German industry over a broad range of capacities. Fig. 13 shows a 50-MW helium turbine plant which has been in operation for several years.

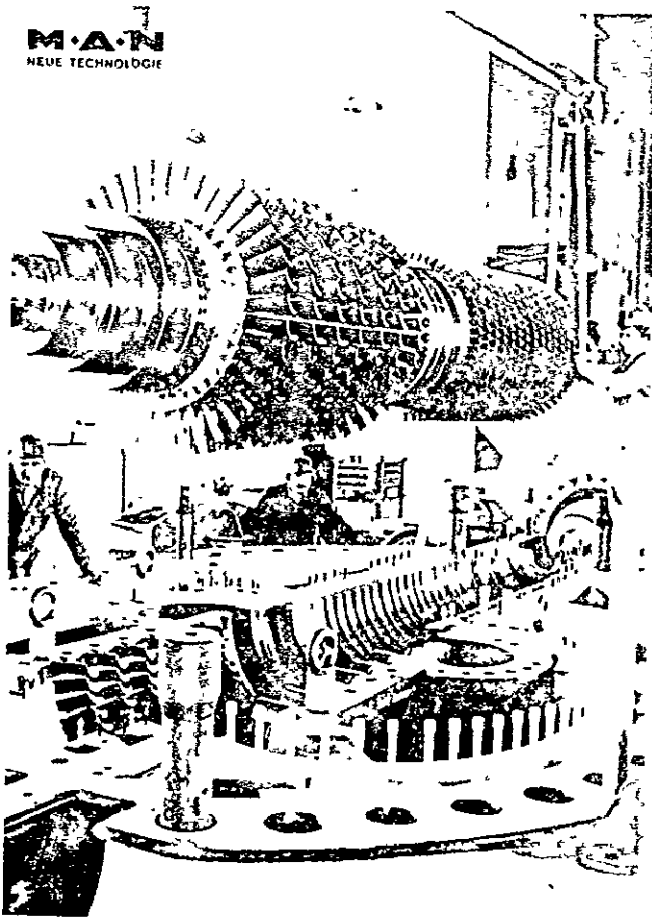


Fig. 13

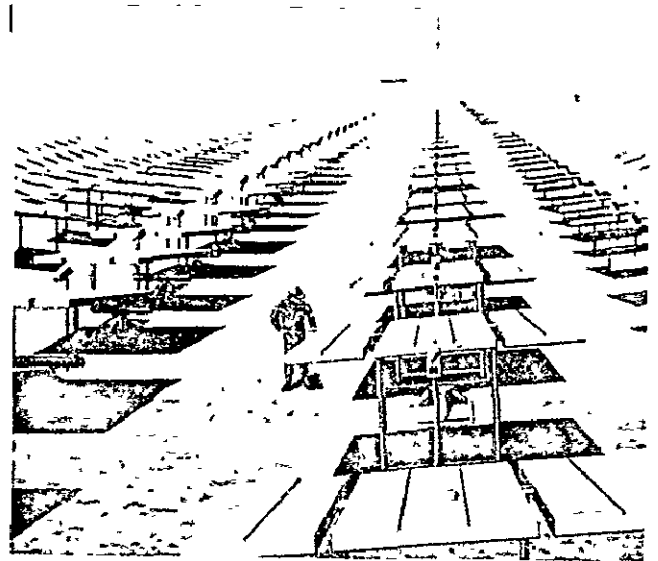


Fig. 14

Besides the initial design concepts for total systems, various firms are engaged in developmental programs on the technology of components and subsystems for solar tower designs. Central absorbers, heliostats and energy converters are being researched.

The MBB Co. is working jointly with Italian and French concerns

on the development and construction of a 1-MW pilot solar-tower plant (Fig. 14) commissioned by the European Economic Community. The solar tower plant operates with steam at about 500° C and has 230 heliostats with a total surface area of approximately 7800 m<sup>2</sup>, which concentrate the sunlight onto a receiver mounted atop a 50-m tower. It is intended that the plant be connected to an existing power grid; it is scheduled to be built in Sicily near Catania and start operation in 1980.

The firms Interatom and M.A.N. are designing a 500-kW solar tower plant under contract from the International Energy Agency (IEA), which is to be built in Almeria, Spain, by 1980. The plant (Fig. 15) will also operate at about 500° C but will employ a sodium-operated high-capacity receiver. Ten nations are involved in the overall project; Interatom is responsible for system guidance and the construction of the sodium receiver, while M.A.N., in close cooperation with the Greek firm Tekem, is undertaking the design and construction of the complete energy-conversion cycle. The firm Energietechnik GmbH, a daughter corporation of RWE, is /31 advising the contractor in all specific questions that may arise from the testing and operation of such power plant systems.

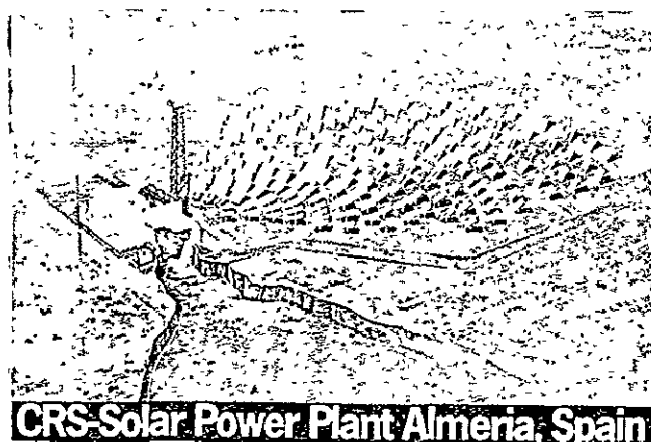


Fig. 15

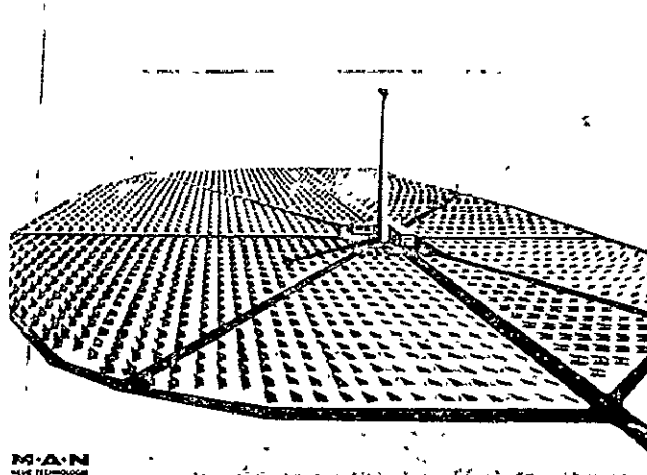


Fig. 16

In addition to these projects, the companies Dornier System, Interatom, M.A.N. and MBB are working jointly within the framework of a national consortium on the development and construction of a high-capacity solar tower, which will be operated at about 850° C with gas as the heat-transfer medium in the receiver (Fig. 16). An open or closed gas turbine will be used in the energy-conversion cycle. Plans are to construct this 20-MW plant, whose development is funded in part by the Federal Research Ministry, in a sun-rich country.

I hope that I have provided you with a concise survey of German activities in the solar-thermal generation of electric power. These developmental efforts are being conducted in the Federal Republic almost exclusively by the member firms of the BSE. The scope and intensity of research activities in industry, which fortunately are supported by the Federal Research Minister, are an expression of the conviction that the utilization of solar energy for electric power generation can make a significant long-term contribution toward broadening the primary energy base.

E. F. Schmidt

The papers presented at this conference cover the entire range of possibilities for the utilization of solar energy, which from an industrial standpoint has already reached the application stage. With the exception of photovoltaic power generation, all the processes involved the conversion of solar radiation into heat, which can then be used for water or space heating. Included is the indirect conversion of solar energy to electrical energy by centralized power plants in the MW range, a technique which is being developed by Europe and the United States for use in southern regions.

In this paper I will report on the technical possibilities of, and developmental work on, the economical operation of decentralized photovoltaic power generation systems, with examples of their advantageous application.

The decentralized distribution of electric-energy-consuming devices in the home, in industry and in communications is ideally matched by the decentralized availability of solar energy on earth. The use of solar generating plants in the multi-kW range is an attractive alternative, therefore, to the construction of complex and high-loss power distribution systems. For economic reasons, the size of a single plant will initially be limited to a few 100 kW in areas with high insolation.

The photovoltaic ("solar-electric") process enables the direct conversion of solar energy to electrical energy and offers the technically-elegant alternative of a fully static system. But

the merits of a system are determined ultimately by the power-generating costs, taking into account the relevant technical, economic and logistic factors for each specific application. In this respect solar generators based on the photovoltaic principle are highly advantageous owing to their practically maintenance-free operation without a cooling medium in the kW range.

The task of developing and producing terrestrial solar generators was taken up in the late 1960s by AEG-Telefunken, the only BSE member active in this area, after advanced communication systems created a need for correspondingly improved power supply systems. The necessary basis for this work was provided by more than 10 years' experience with space technology in many international projects. In the area of spacecraft power supply systems with solar generators, AEG-Telefunken has become the leading European concern: As is known, solar generators have been the principal energy source for both manned and unmanned space missions ever since space travel began, for only these static systems can meet the necessary extreme technical criteria. With the development of terrestrial generators based on solar cells made from unconventional silicon base material with efficiencies greater than 10%, AEG-Telefunken has laid the groundwork for advanced terrestrial generator designs.

### Solar Generator Technology

The solar-generator power supply system is designed entirely in modular form as a static energy converter which covers the range from a few watts up to several 100 kW. The conversion of the radiant energy of the sun into direct electric current is accomplished by solar cells, which are mechanically and electrically integrated into generator modules. The specific power output of an individual solar cell depends on material parameters and on such operational parameters as temperature and ambient conditions.

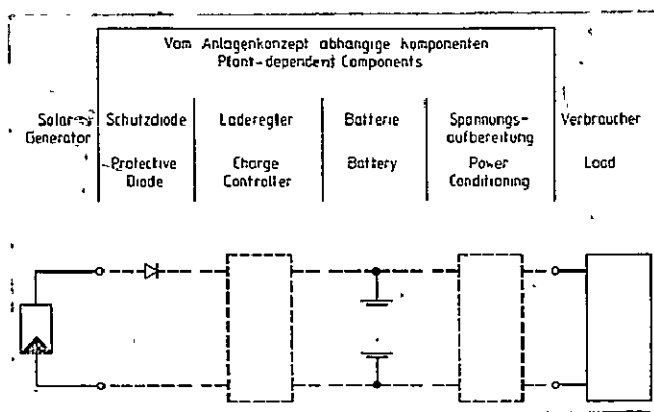


Fig. 1. Photovoltaic power supply systems.

modified by rectifiers and inverters to supply the various loads with the necessary form of electric energy.

Energy conversion in the silicon solar cell is based on the photovoltaic effect in solid materials, which requires the presence of a barrier layer between two oppositely-charged regions of a semiconductor: n-material with an excess of negative electrons, and p-material with a corresponding excess of positive "holes." The principle of the conversion of solar radiation to electricity has been known for more than 100 years and has its most familiar application in the photographic light meter. The photovoltaic process in an illuminated solar cell can be divided into the following three phases:

- Absorption of light and production of charge carriers in the semiconductor
- Separation of the charge carriers
- Diffusion of the charge carriers in regions with like charge.

[Omission] thereby forming charge carriers whose energy at least reaches or exceeds a certain value.

/33

In early 1975 a 3-year program supported by the Federal Ministry for Research and Technology was begun for the purpose of investigating materials and manufacturing methods with regard to their suitability for the construction of economical solar generators. In the first phase of this program, the techniques for manufacturing the silicon base material and solar cells for spacecraft applications were retained, but without the extremely costly control steps. Wiring the individual solar cells into modules was also done by applying the weld-joining technique developed for space technology.

The main developmental effort could be concentrated on the mechanical integration of the solar cell modules and their hermetic encapsulation. In view of their long-term service, the encapsulation materials must meet stringent requirements in terms of resistance to UV radiation, thermal cycling, moisture, erosion, air impurities, etc. As a result, two module types were developed, built and successfully tested:

- The compound glass system with the solar-cell composite imbedded between two glass sheets.
- The plastic system with the solar-cell composite imbedded in a fiberglass-reinforced casting resin.

In a subsequent phase, novel techniques were employed in the manufacture of the base material and solar cells. In continuation of the close [omission] manufacturer Wacker-Chemitronic, AEG-Telefunken made a decisive step in the fall of 1976 toward developing economical solar generators of the future: The modules in Fig. 2 consist of 10 x 10-cm solar cells which are fabricated from unconventional base material. These modules demonstrated for the first time that the costly manufacture of single-crystal starting material with a limited, circular cross-section could

be surmounted by the production of a special polycrystal material. Even these first terrestrial modules with large-area solar cells showed efficiencies of about 10%. Within the framework of this experimental study, the various techniques were applied in the construction of a test generator with an output of approximately 1 kW, which was delivered to the university of Stuttgart.

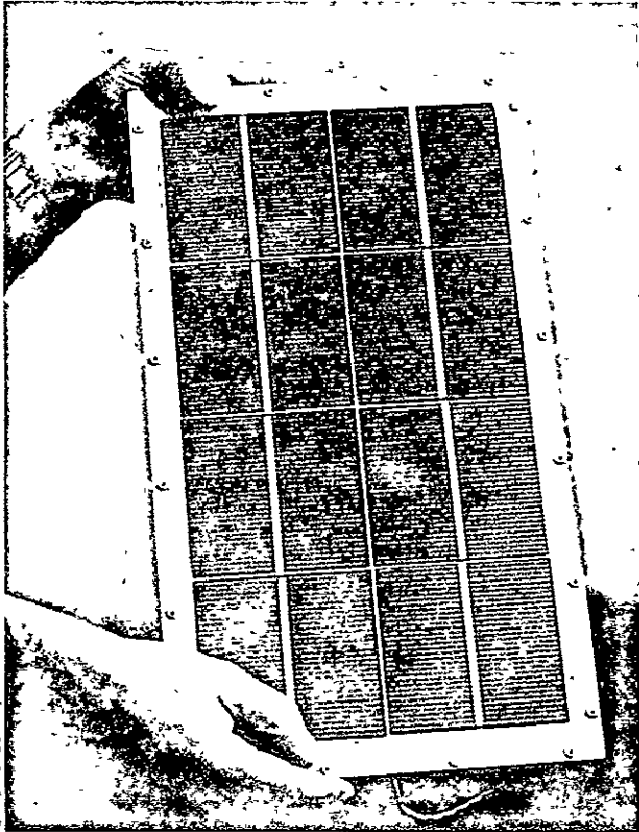


Fig. 2. Module of 8 10x10-cm polycrystalline silicon solar cells.

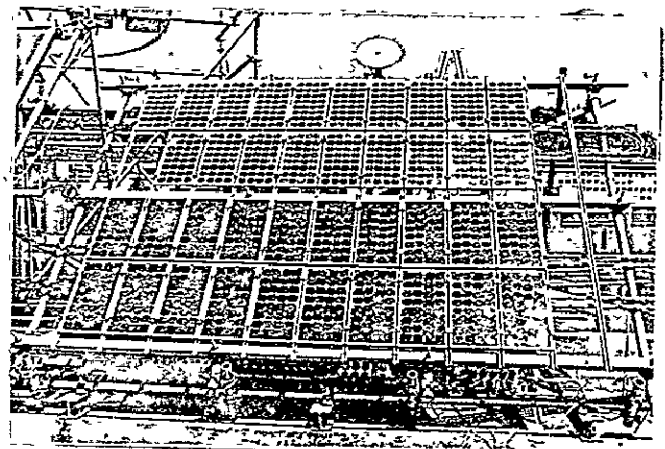


Fig. 3. Test generator (University of Stuttgart, Germany).

### Solar Generator Applications

The early involvement in the development of terrestrial solar generators was prompted by the market demand for special power supply systems and was intensified by the increasing efficiency of such systems in space technology. Similarly, devices and systems

in power and communications technology are increasingly requiring the use of completely new technologies to provide optimal service and meet special applications. Improvements have been particularly great in the electronic devices used in these systems in terms of their efficiency, size, reliability and maintenance requirements, thereby creating a pressing need for corresponding improvements in associated power supply systems. Furthermore, there has been increased export in recent years to countries with a weak infrastructure, with a consequent need for highly simplified power supply systems corresponding to local conditions. The prospects offered by developing countries which are starting to build an infrastructure by supplying power to village communities for communication links, agriculture, water projects, etc. and are starting to mechanize are of particular interest in this regard.

The previous field testing and commercial use of solar generators, which are increasingly [ommission] have confirmed the special advantages of photovoltaic systems:

/34

- modular construction
- simple, inexpensive installation
- extremely long service life with low maintenance
- absence of a cooling medium as a heat sink
- conversion of direct and diffuse sunlight of varying intensity at a constant level of efficiency.

The modular construction of a solar generator out of a number of identical modular units leads to considerable advantages in power supply systems. The upper module size limit is optimized according to the requirements of economical manufacture, installation and maintenance. Reliability aspects must also be considered, so that the entire system can remain operational if a few modules fail, and repairs can be done at a later time without interrupting operation. The modularity permits simple adaptation of the systems

to a growing power demand, which means an economical utilization of investment funds. This is particularly important during the initial phase of operation, since the user can test the feasibility of solar generators for his particular application with a relatively small investment. Finally, the simple construction of the easy-to-handle generator modules permits their cost-effective installation by trained personnel.

The service life of these static power-generating systems is practically unlimited. It is necessary, however, that the metal contacts and connectors of the solar-cell modules be suitably enclosed to protect them against moisture and oxygen, primarily. If the transparent surface is protected to some degree against extreme mechanical abrasion (e.g., by sandstorms), maintenance of the modules is limited basically to periodic cleaning. In contrast to the requirements of conventional power-supply systems in terms of special equipment and trained repair and maintenance personnel, a solar maintenance personnel, a solar generator system requires practically no supporting infrastructure.

The complete utilization of the diffuse radiation component by solar generators represents a considerable advantage, since even in southern regions a slight cloud cover can cause this component to increase significantly. For this reason the common practice of achieving economy by the supplementary use of concentrating collectors would appear to be of little benefit in most cases: The cooling required by the loss of solar-cell efficiency with increasing operating temperature leads to further disadvantages. For these reasons, developmental efforts are centering on the simple flat-plate collector design (with the exception of special applications requiring low concentration factors).

Photovoltaic solar generator systems are available in the lower capacity range from a few watts up to 1 kW [omission] buoys.

radio installations with decentralized and automatic operation, ground receiving stations, electric traffic signals as well as land and maritime radio beacons, including signal buoys. The simplicity of the loads often allows the solar generator to be directly connected to a storage battery. Systems with outputs below 100 W can be considered state-of-the-art and are already competitive with conventional systems in this range. Fig. 4 through 7 show examples of such systems used in communications technology. A further reduction in solar generator costs will greatly expand this application in the near future.

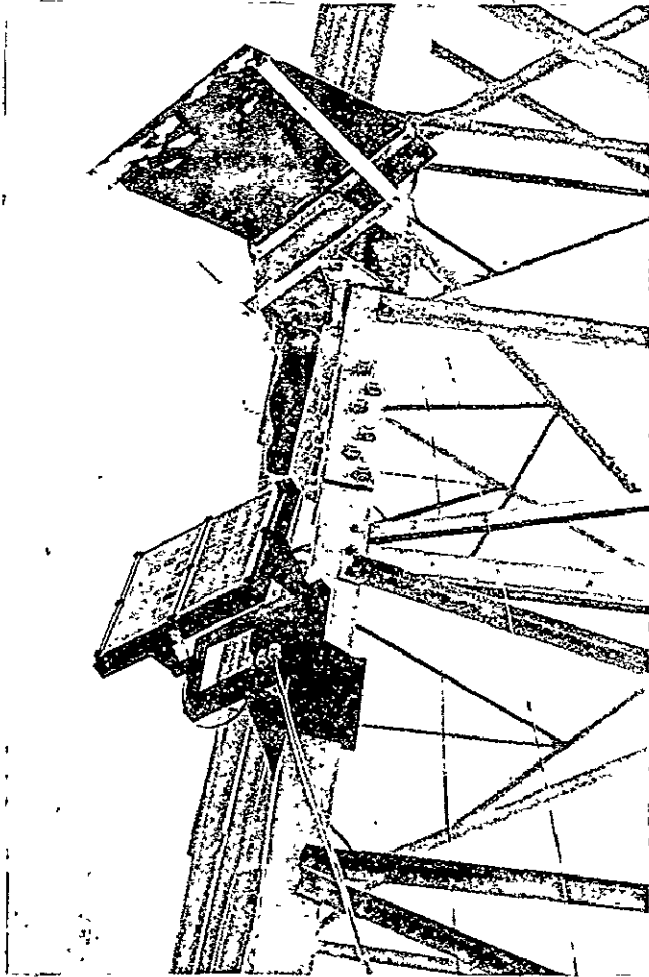


Fig. 4. Automatic solar-generator measuring station (near Vienna, Austria).

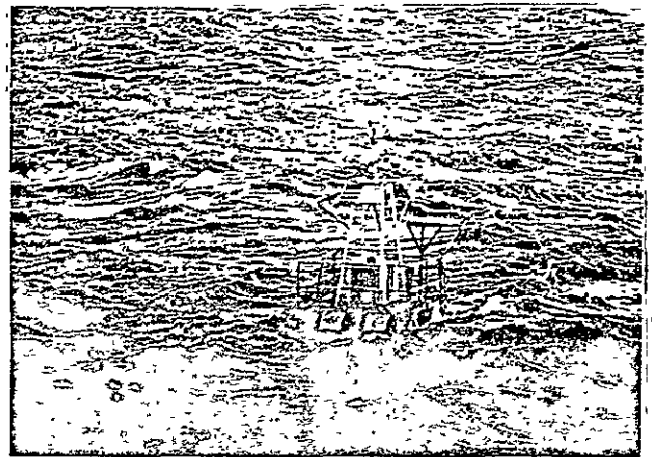


Fig. 5. Buoy in the Red Sea

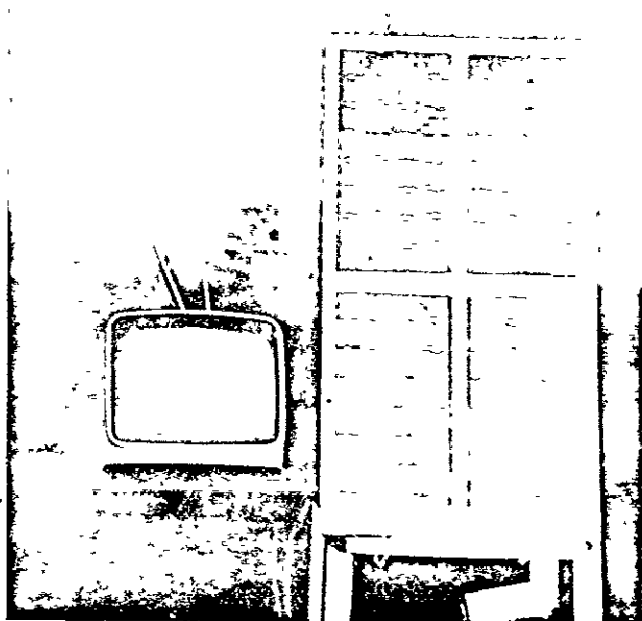


Fig. 6. Educational television system (Sudan).

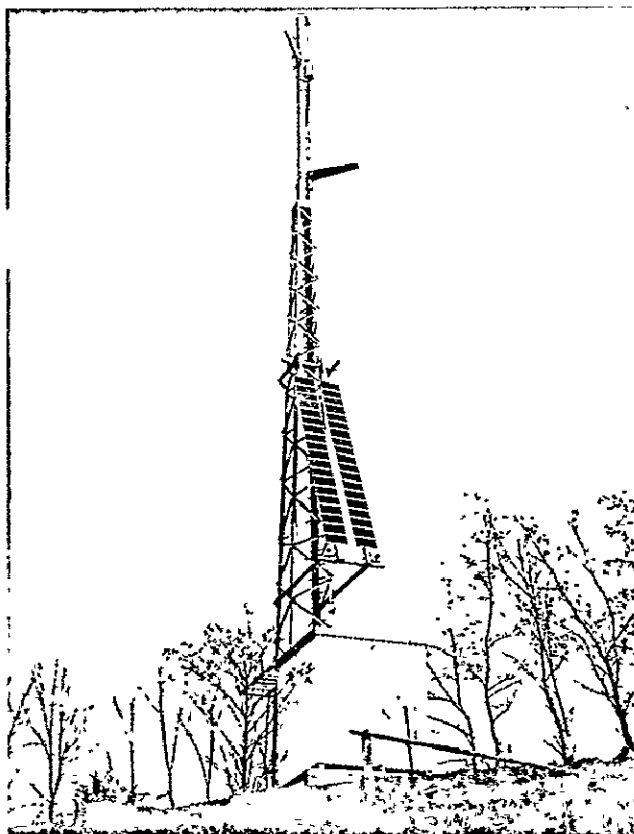


Fig. 7. Television transmitter (Lasel, Germany).

Potential areas of application in the intermediate range up /35 to 10 kW include fixed radio relay systems, radar, airport lighting, traffic control systems, civilian and military emergency power supplies, as well as decentralized building power supplies. The latter application appears to be particularly attractive with regard to the combined production of electrical and thermal energy. The relay-station power supply of the Iranian Postal Service shown in Fig. 8 and the solar-driven water pump shown in Fig. 9 are sample applications in this range of power outputs.

From today's perspective, the size of a photovoltaic solar generator plant is limited to an output of a few 100 kW. Thus, the upper range of outputs from 10 to about 500 kW is sufficient

for powering large military radar stations, civilian emergency power supplies as well as power-supply plants for village communities in arid regions. Of course the absence of a need for a storage system, assuming discontinuous operation is permissible, would favor the use of solar generator systems.

### Solar Generator Development

The economy of solar generator systems in the multi-kW range will require considerable developmental effort during the next decade. Preliminary efforts have already led to a comprehensive /36 eight-year development program whose purpose is to lower the costs of solar generators by several orders of magnitude during the next decade by adopting novel manufacturing techniques. This program is based initially on the application of known manufacturing techniques, so that only processes or technologies which are now known will be employed. This is made possible by the use of silicon, which is available in practically limitless quantities, as the starting material.

The large number of manufacturing steps with a correspondingly high power consumption has resulted in terrestrial solar-cell costs of about 50 DM for each installed watt. The cost is approximately the same for integrating the solar cells with the generator, for installation, and for modifying the energy output. The development program for cost reduction encompasses all system components and was undertaken on a full scale in July of 1977.

The developmental activities of AEG-Telefunken can be summarized as follows:

- Development of novel silicon solar cells, joining and encapsulation techniques, and of cost-effective electronic voltage transformers and regulators which are optimally adapted to the load.

- manufacture of generator prototype plants up to several 100 kW at fabrication plants set up in stages.
- Worldwide field-testing of solar generators under a wide variety of climatic conditions.
- Development of optimally-adapted systems for important applications with worldwide cooperation, e.g.:
  - solar water-pump systems (0.5 to 5 kW)
  - solar water heating (1 to 10 kW)
  - solar television reception (50 to 200 W)
  - solar communication links (0.1 to 5 kW)
  - solar traffic control (0.2 to 2 kW)
- Feasibility studies on photovoltaic power-supply systems up to 1 MW.

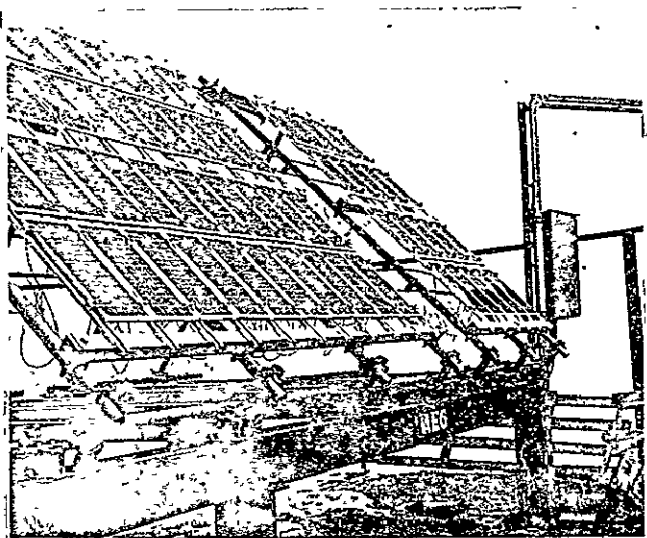


Fig. 8. 2-kW solar generator for a radio relay station (near Tehran, Iran).

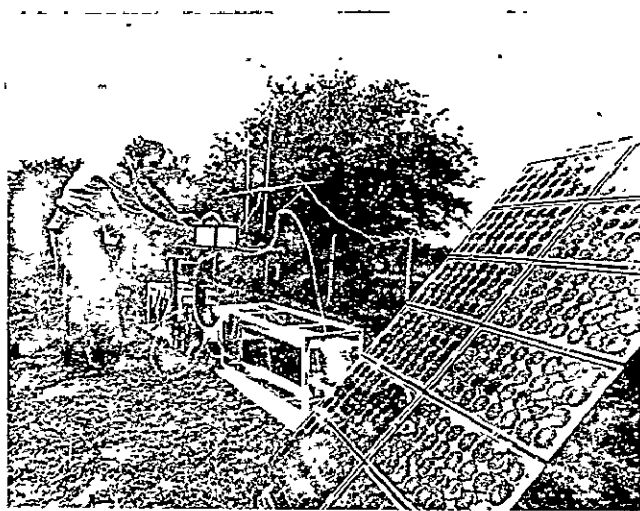


Fig. 9. Water-pump test stand.

In conclusion, it must be pointed out that the results of extensive market analyses conducted by us fully support the

development of these attractive power-supply systems. If events continue to confirm the experience that preliminary estimates tend to be entirely too cautious, it is quite possible that the upper capacity range of terrestrial systems will be raised in the future.

The coming years will be characterized by the gradual introduction of solar energy systems on the market, accompanied by increasing individual system capacities.